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ARTIFICIAL RECHARGE STRUCTURES FOR GROUNDWATER SUSTAINABILITY IN KRISHNA RAJA NAGARA TALUK OF KARNATAKA STATE, INDIA USING GEOSPATIAL TECHNOLOGY

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Abstract: The water levels in Krishna Raja Sagara (KRS) reservoir depended mainly on the southwest monsoon over Karnataka, especially at the Cauvery catchment area and its inflow. The Krishna Raja Sagara (KRS) reservoir with the gross capacity of 49.45 thousand million cubic feet (tmc ft) and maximum water level is 124.8 ft that quenches major cities of Bengaluru, Mysuru, Mandya and other 47 towns and 625 nearby villages for their daily needs. With water levels drastically receding during extreme hot conditions in the Cauvery basin, Bengaluru is more likely staring at severe drinking water shortage. Water scarcity issues may arise in upcoming years due to its demand especially in industrial sectors of Bengaluru city, low rainfall conditions, rapid evapo-transportation due to extreme summer seasons and global warming (?). The present work deals with the utilization of GIS based Analytical Hierarchy Process (AHP) technique to delineate best sites to modify surface run-off through limited field visits. SoI toposheet, IRS-LISS-III and ASTER DEM data are collected to achieve present aim. All the important thematic layers have been digitized and overlaid one above the other to produce desired output in GIS environment. Each generated thematic maps have been assigned suitable weightages using AHP depending on the features priority to derive suitable sites for groundwater augmentation. The final results highlight the best sites for Artificial Recharge Structures (ARS) in decision making process which is a suitable model for similar geological terrain using AHP approach.

Keywords: Krishna Raja (K.R) Nagara; LISS-III; Geospatial Technology; ARS; AHP.

I. INTRODUCTION

Krishna Raja Sagara (KRS) reservoir is the major source of water for the city's residents of Bengaluru, Mysuru, Mandya and other surrounding areas to meet their drinking water requirements. The gross storage within the reservoir was 22.44 tmc ft on Tuesday (21st July 2021) as against 28.81 tmcft on the same day last year. The gross capacity of the reservoir is 49.45 tmcft with the current storage is only 45% of its actual capacity. Though the onset of the south-west monsoon was timely and the catchment region of the Cauvery received copious rain till the third week of June-2021, the rain abated later on and the inflow into the dam depleted. The increasing demand for water for the domestic, irrigation and industrial sectors has created increasing pressure on this natural resources that could be a purpose of concern in extremely inhabited and industrialized nations such as India, China and African country (Tanveer Dar et al, 2020; Das et al., 2017; Manap et al., 2011). The searing heat during summer seasons showed maximum temperature between 35^0C to 37^0C across Mysuru-Mandya belt. This has brought the main focus on drinking water situation in the region as water levels within the reservoir is susceptible to depletion because of high evaporation loss and release to the canals. Though the water levels in KRS is depleting, it was sufficient to last through summer (Mar/April-2022). The situation is not as precarious compared to the recent past, if the monsoon does not set in on time. With increase in temperature during next summer seasons, the water level in KRS will deplete quickly and hence the residents of Bengaluru's suburbs and 110 villages would suffer from water scarcity as bore wells already running dry at the depth of 1,100 ft. Bengaluru city alone requires 1.5 tmcft of water per month and any release of water for agricultural activity with the delay of southwest monsoon could lead to a scarcity crisis.

The remote sensing methodology offers systemic, synoptic, and fast repetitive region coverage as a result and a crucial tool for acquiring short-run spatio-temporal data of regional scale (Leblanc et al., 2003; Tweed et al., 2007; Tanveer Dar

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et al, 2020). GIS provides a platform to effectively handle comprehensive and complicated spatial-temporal information (Imran Ahmad et al, 2010; Wieland & Pittore, 2017). Efforts have been made on Toposheets in digitization and extraction of the base maps through Visual Image Interpretation Techniques (VIIT); whereas Digital Image Processing (DIP) (Manjunatha et al, 2019) have been applied on PAN+LISS-III (Basavarajappa et al, 2014b) and ASTER G-DEM (Global Digital Elevation Model) in ArcGIS environment (Manjunatha et al, 2015a). All the layers are then converted into raster format to overlay orderly one above the other by assigning appropriate weightages (Harish Chandra et al., 2014). Remote sensing and GIS coupled with the AHP approach in identifying potential groundwater recharge zones are carried out by few. Several studies are applied to identify most suitable for artificial recharge structures in India (Ghayoumian et al 2007; Krishnamurthy and Srinivas, 1995; Krishnamurthy et al., 1996; Saraf and Choudhury, 1998). Thomas Saaty's (1980) Analytical Hierarchy Process (AHP) has been adopted for assigning ranks to each class (Manjunatha et al, 2019). All parameters have been overlaid using weighted overlay analysis and results have been schematically obtained (Dinakar S, 2005). Employing GIS, RS, and AHP along with the elimination indices is used for developing data in several thematic layers and integrating them with sufficient accuracy within a short period of time (Hamid Kardan et al, 2017).

II. METHODOLOGY

A. Study Area: The study area located in between $76^0 08'$ E to $76^0 30'$ E and $12^0 23'$ N to $12^0 39'$ N with an aerial extent of 622.74 km^2 (Manjunatha et al., 2021a). The general elevation recorded at 788 mts above MSL (Fig.1a). Actual rainfall recorded for the year 2005 is 923.5 mm with 59 rainy days (CGWB, 2012). The main Cauvery River flows from west to eastern direction in the central parts of the taluk and drains major parts by fulfilling the canal irrigation (District at a Glance: 2012-13; Basavarajappa et al, 2014a).

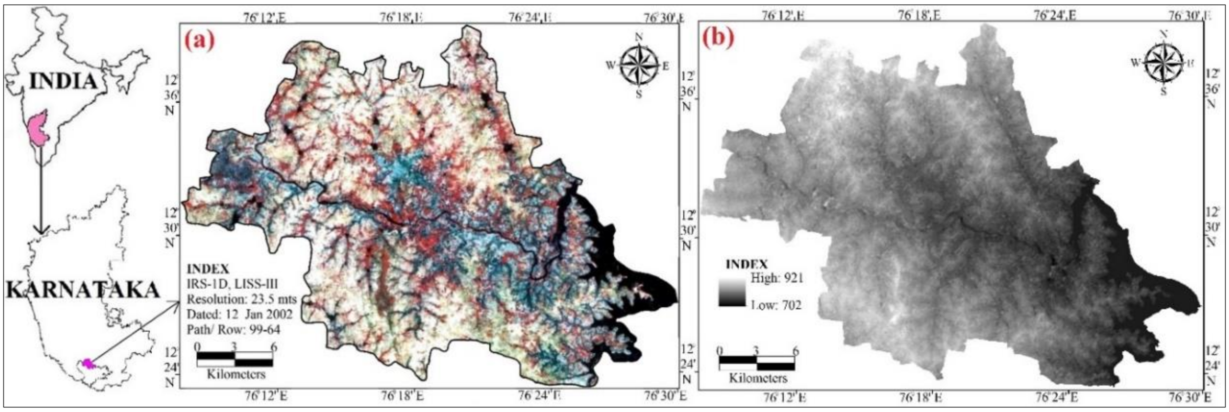

Fig.1. (a) LISS-III and (b) ASTER GDEM Satellite image of K.R. Nagara taluk

B. Materials Used

i. Base Map: Survey of India toposheets of 57D/2, 3, 6, 7 and 11 in 1:50,000 scale (Fig.1a) acquired from Survey of India (SoI) Office, Govt. of India, Bengaluru.

ii. Satellite Data: IRS-1D LISS-III of 23.5m Resolution and PAN of 5.8m (Nov-2001 & Jan- 2002), are acquired from National Remote Sensing Agency (NRSA), Hyderabad (Manjunatha et al., 2020b).

iii. GIS Software's: Erdas Imagine v2011 and Arc GIS v10 (Manjunatha et al, 2021b).

iv. GIS techniques: Visual Image Interpretation Techniques (VIIT) and Digital Image Processing (DIP).

v. GPS: Garmin 12 is used to demark exact locations and to check the conditions of the each selected sites during limited field visits (Manjunatha et al., 2020a).

III. RESULTS & ANALYSIS

A.1 Lithology: Lithology plays a major role in the availability and occurrence of groundwater. The type of lithology present affects the recharge of groundwater (Shaban et al., 2006; Tanveer Dar et al, 2020) as it controls the percolation (Tanveer Dar et al, 2020). The map is prepared by on-screen digitization from District-Quadrangle map of GSI (Geological Survey of India) number 48P and 57D of 1:250,000 scale through ArcGIS. Archeaen and proterozoic age group of rocks are well exposed, underlain by hard rock terrain consisting of amphibolites, metapelitic schist, calc-silicate rock, migmatites & grano-diorite-tonalitic gneiss (Fig.2a). Migmatite, granodiorite, tonalitic gneisses are wide spread; whereas dolerite dykes, limestone & dolomite are noticed rarely in the study area. Amphibolites with pelitic/ metapelitic schists are randomly spread around the taluk; whereas schistose rocks are noticed as parallel hill ranges. Naturally exposed weathering granitic-gneisses noticed along discontinuities and causes complex weathering profiles during field investigations (Manjunatha and Basavarajappa, 2015b). Basement rocks are observed at shallow depth with more intense

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of structural faults & joints resulting in rock weathering profiles. The study area represents mainly of gneisses, granitoids and schistose formations and act as crystalline formations for groundwater movement and storage.

A.2 Geomorphology: The map is derived from Geomorphology map of Karnataka of 1:250,000 scale (Basavarajappa et al., 2012) representing the plainlands to undulating regions with major Cauvery River flowing in central parts of the study area. Geomorphology describes the region's shape & topography and plays a vital role in groundwater availability and distribution (Tanveer Dar et al, 2020; Karanth, 1987). It is one among the main characteristic factor used to recognize groundwater prospect zones (Arulbalaji et al., 2019; Tanveer Dar et al, 2020). The study area is dominated by pediplain shallow feature attributed to very good to moderate recharge zones; whereas valley fills are extremely favorable for groundwater occurrences and acts each as recharge & discharge areas for groundwater (Ramaiah et al., 2012). The water table depths are relatively shallow near perennial surface water bodies and topographically low areas (Fig.2b). Valley fill shallow and pediplain moderate are very good to good recharge zones and considered most favorable zones for groundwater prospects; while pediplain shallow areas are good to moderate. Pediment inselberg complex and pediment zones are moderate to poor; whereas residual hills & inselbergs thought of as poor to terribly poor recharge prospect zones (Manjunatha et al., 2020b). River/stream, reservoir, reservoir islands and hills are not suitable for ARS among delineated landforms. All the geomorphic units have been digitized and their aerial extent are provided in Table.1.

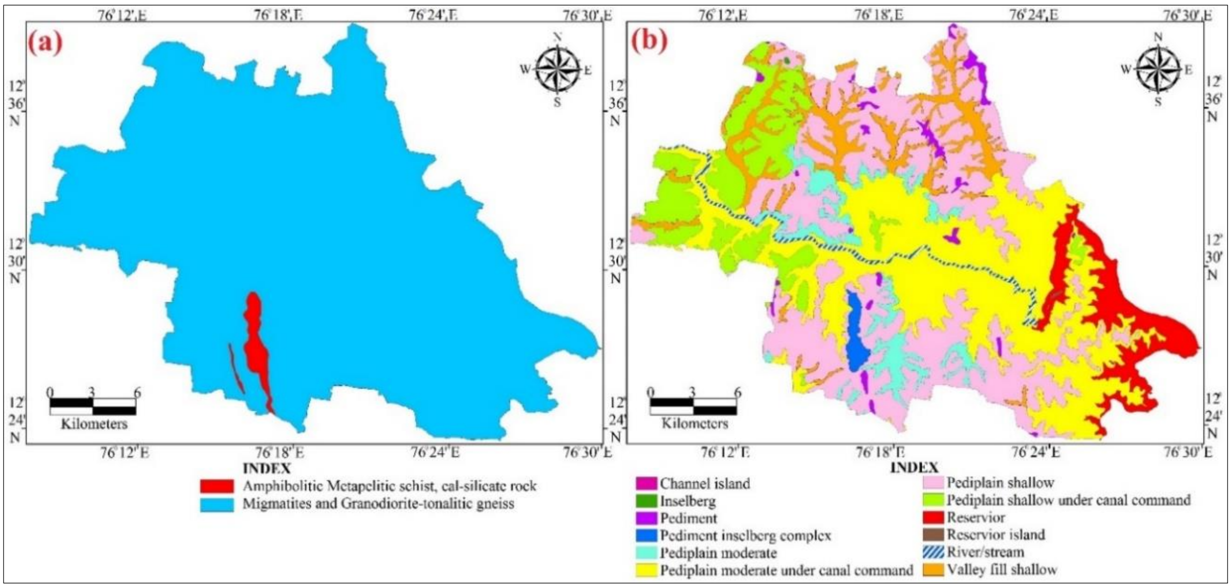

Figure 2. (a) Geology and (b) Geomorphology map of K.R. Nagara taluk

Table.1. Areal extent of Geomorphological features of K.R Nagara taluk

Sl No.	Geomorphological units	Area in km^2	*Percentage (%)*
1.	Channel island	0.075	*0.01*
2.	Inselberg	0.859	*0.13*
3.	Pediment	9.234	*1.48*
4.	Pediment inselberg complex	6.078	*0.97*
5.	Pediment moderate	29.946	*4.80*
6.	Pediplain moderate under canal command	194.622	*31.25*
7.	Pediplain shallow	203.938	*32.74*
8.	Pediplain shallow under canal command	68.825	*11.05*
9.	Reservoir	42.665	*6.85*
10.	Resevoir island	0.171	*0.02*
11.	River/ stream	8.766	*1.40*
12.	Valley fill shallow	55.416	*8.89*
	Total	***620.595***	***99.59***

A.3 Drainage & its density: Drainage patterns are digitized from SoI topomap and overlaid on PAN+LISS-III image of 5.8m resolution (Fig.3a) (Manjunatha et al, 2020b). Cauvery is the major river system traversing the study area from west

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to east at central part. Paddy, ragi, pulses cotton, sugarcane, jowar, tobacco and oilseeds are the major agricultural practices occupied in the study area (Seyed Reza Hosseinzadeh, 2011). Cauvery River drains entire taluk showing dendritic to sub-dendritic type of drainage pattern having uniform control of bedrock over water flow in the basin (Basavarajappa et al., 2016). River Cauvery flow in high volume to KRS reservoir when heavy rainfall occurs in monsoon seasons filling the surface water bodies/ tanks which is mainly utilized for agriculture purposes. Drainage density (Dd) is significant as a factor determining the travel time by water in a terrain (Fig.3b). The high drainage density indicates the closeness of channels spacing; while low drainage density results in highly resistant or permissible sub soil materials, dense vegetation and low relief (Manjunatha et al, 2019). Higher Dd implies higher surface water runoff which become difficulty in ARS due to low infiltration of water; whereas low Dd implies less surface runoff and will be highly suitable (Manjunatha et al, 2019). Ranks and weightages are assigned based on the priorities of raster resultant maps as shown in the Table 5 & 7.

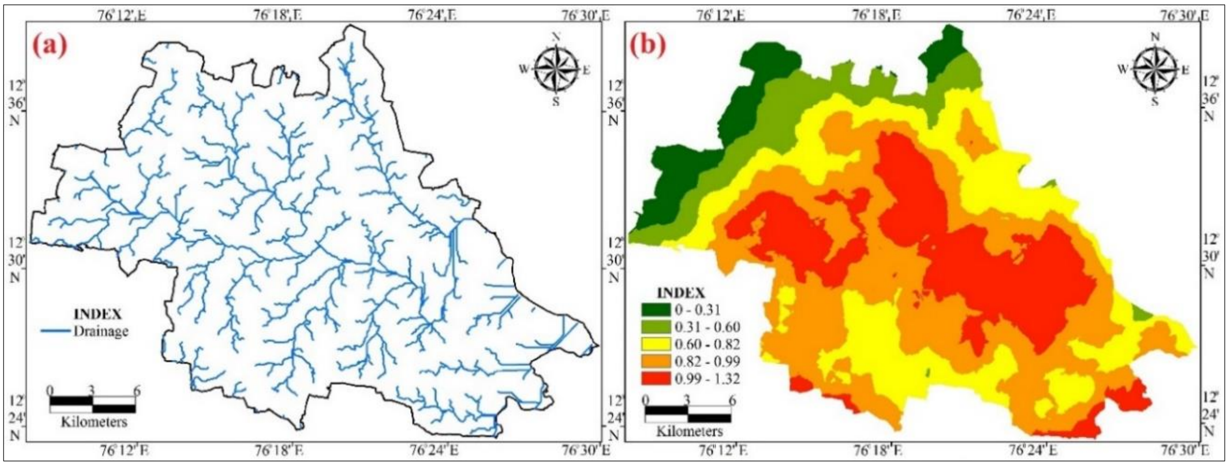

Fig.3: (a) Drainage map and (b) Drainage Density map of K.R Nagara taluk

A.4 Lineament & its density: Lineaments are digitally extracted from PAN+LISS-III image of 5.8m resolution using PCI Geomatica and ArcGIS software's (Fig.4a) (Basavarajappa et al, 2015; Manjunatha and Basavarajappa, 2017). Prominent lineaments are seen oriented in a NNE, SSW and N-S direction. These are the landscape exhibiting underlying geological structure such as subsurface faults, fractures and seepage areas influencing the occurrence of groundwater acting as canals and reservoirs influences the groundwater occurrences. Fracture/ fissure/ shear plane system developed together with joints and faults facilitates the groundwater circulation and hold moderate amount of water (Manjunatha and Basavarajappa, 2015b). Dykes are most important in controlling regional subsurface water flow and act as a conductor based on intensity of faults and fracturing (Mohamed Babiker and Agust Gudmundsson, 2004). Faults/lineaments act as conduits and very good aquifers, on the other hand faults act as drains, lowering the water table and thus affecting the distribution of groundwater resources. Faults act as barriers to the groundwater flow, if filled with impermeable material such as silts and clays (Mulwa et al., 2005; Idris et al, 2018). Lineament density (Ld) are generated digitally on LISS-III satellite image using Line Density tool of ArcGIS software which ranged from 0.00 to 0.64 m/m^2 (Fig.4b). The major structural features that are impacting on the groundwater are fractures are subdivided into joints, fissures and faults, which are formed by brittle fracturing of rocks. The rocks in these units are hard & compact acting as run-off zones and limited infiltrations are noticed along the weak planes of joints, faults, fractures, folds and dykes (Manjunatha et al, 2019; Senthil Kumar et al, 2015). Low Ld indicates the more suitability; whereas very high Ld indicates less suitability for ARS.

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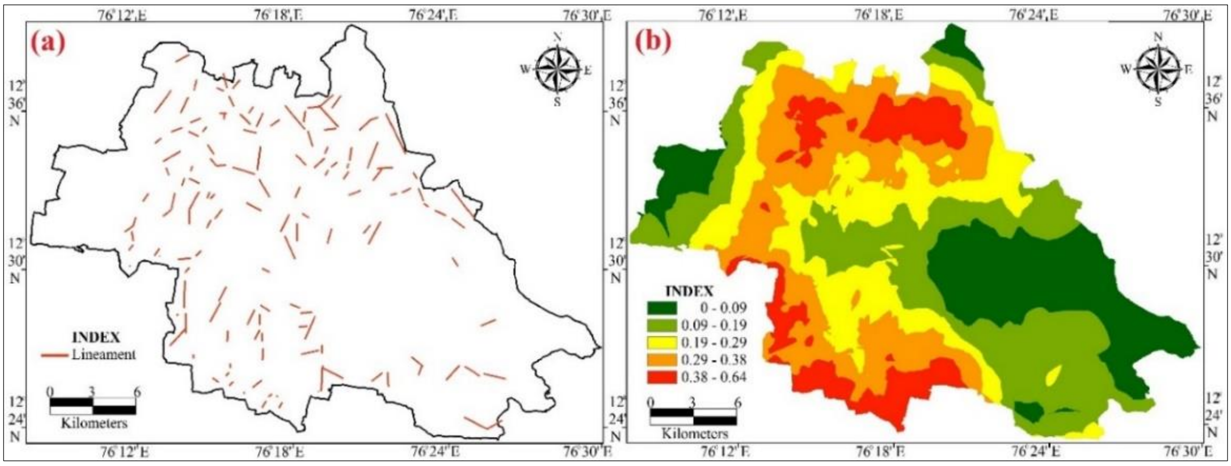

Fig.4 (a) Lineament map and (b) Lineament Density map of K.R Nagara taluk

A.5 Soil: Soil is also an important parameter that affects the occurrence, distribution of groundwater and plays a significant role in the infiltration of water, therefore it affects the recharge of groundwater (Tanveer Dar et al., 2020; Ibrahim-Bathis & Ahmed, 2016). The soil texture and hydraulic properties are key factors in estimating infiltration rates (Tanveer Dar et al., 2020) which determines the specific type of ARS to be located (Siddan et al, 2005). The clayey soil type is noticed to be cover major parts of the study area that are derived from granitic-gneisses and schistose rocks (Fig.5a). Clay soil is deep and moderately, well drained and slight salinity in particles (Basavarajappa et al, 2013). Clay-skeletal type of soil shows very deep and well-drained with slight erosion (Basavarajappa et al, 2013). Rocky land type of soils are connected with deep and gently sloping interfluves showing slight erosion (Basavarajappa et al, 2013). Ranks and weightages have been assigned (Table.5 & 7) based on soils infiltration capacity in the study area.

A.6 Slope: The steep slopes will lead to quick runoff, greater soil erosion rates with a little groundwater recharge (Magesh et al., 2011a; 2011b). Slope map is derived digitally from ASTER GDEM of 30m resolution based on the guidelines of All India Soil and Land Use Survey to determine the slope categories (Fig.5b) (Love Kumar., 2017). Slope determines the rate of infiltration and run-off of surface water (Devendra singh and Sharma, 2017). Flat surface lands are highly suitable for ARS, since it implies lower surface run-off; while higher slope increases the run-off which makes the site not suitable for ARS. The taluk representing partly plain ground to undulating with general slope trending from west to eastern region. 'Very Good' Artificial Recharge Structures category falls under of 0^0 to 3^0 which is a nearly flat terrain having high infiltration rate (Manjunatha et al, 2019). 'Good' ARS category ranges from 3^0 to 7^0 representing slightly undulating and some amount of runoff. 'Moderate' ARS category ranges from 7^0 to 11^0 which imply high runoff and low infiltration. 'Poor' ARS category ranges from 11^0 to 18^0 representing a moderate to steep slopes; whereas 'Very Poor' ARS category ranges from 18^0 to 40^0 representing higher slope and higher runoff (Fig.5b) (Manjunatha et al, 2019). These categories have been divided into five classes and ranks, weightages are assigned as shown in the Table.5 & 7.

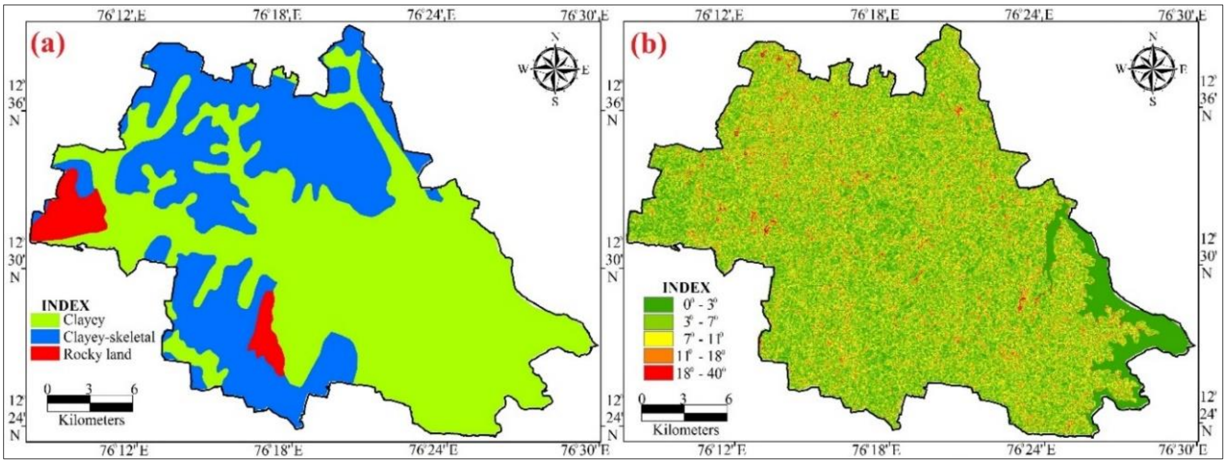

Fig.5: (a) Soil map and (b) Slope map of K.R Nagara taluk

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A.7 Land use/ land cover (LU/LC): The LU/LC map is generated on LISS-III satellite image of 5.8m resolution using Supervised classification analysis in ArcGIS (Fig.6a). Land is one among the non-renewable resources and its mapping is vital in land and water resource development (Manjunatha et al, 2021b). Land use describes how a parcel of land is used such as agriculture, settlements or industry, whereas land cover refers to the natural cover such as rocks, water bodies, hills, vegetation cover on the earth's surface (Anderson et al., 1976; Brebbia and Viktor, 2011; Manjunatha et al., 2021a). LU/LC regulates volume, timing, and recharge amount and also impacts runoff and evapotranspiration (Tanveer Dar et al, 2020). 87% of the study area comes under agricultural practices; while only 9% covered by water bodies of major east flowing Cauvery River, surface tanks and others. Agricultural land, built-up land, forest cover, waterbodies, wastelands and others features have been digitized and their aerial extent are provided in Table.2.

Table.2 Land use/land cover categories of K.R Nagara taluk

Sl. No	Land categories	Area in km^2	*Percentage (%)*
1.	Agricultural land	542.6862	*87.14*
2.	Built-up land	10.9128	*1.75*
3.	Water bodies	57.9411	*9.30*
4.	Wastelands	3.5746	*0.57*
5.	Others	7.6118	*1.22*
	Total	***622.7265***	***99.98***

A.8 Stream Order: (Sμ): Stream order is the first step in any drainage basin analysis. Stream order map is derived digitally from ASTER GDEM image (Fig.6b) (Love Kumar., 2017). The terrain is characterized by flat land to steep slope and medium precipitation with higher stream order is associated with greater discharge (Fig.7b). The variation in the total number and total length of the streams are due of precipitation, morphology and lithology of the terrain (Manjunatha et al, 2019). The basin order goes up to fifth number of streams represents in each order denoted as 1st, 2nd, 3rd, 4th and 5th stream orders . 2nd, 3rd or 4th stream orders are suitable for Storage Tank and Percolation Tank type of ARS (Table.5 & 7) (Manjunatha et al, 2020b).

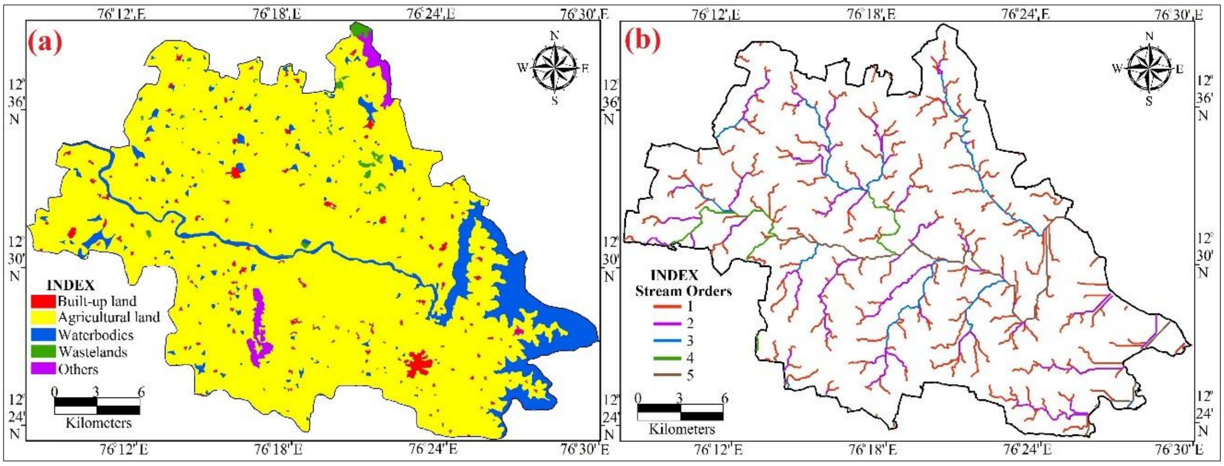

Fig.6: (a) Land Use/Land Cover map and (b) Stream Order map of K.R Nagara taluk

B. Analytical Hierarchical Process (AHP): Analytic hierarchy process (AHP) is a broadly accepted multi-criteria decision making method developed by Saaty (1980) and utilized as an efficient method for solving several environmental issues (Diaz-Alcaide and Martinez-Santos, 2019; Manjunatha et al, 2020b). The complex data of all thematic layers can be converted into simple output map using integration of GIS and AHP (Tunahan Aykut, 2021). This approach permits the crowd decision making where planners can use their scientific practice and knowledge to fail a problem into a hierarchy structure and solve it by the AHP process. AHP method is based on the principles of differentiation, pair comparison, and priority of choices. Correct analysis and evaluation in multivariable decision making within recent decades have become the most powerful programming method with a perfect framework for complicated decision making. From centre towards the right side the value increase from 1 to 9 and towards the left side the value decrease from 1 to 1/9 (Table.4). Each parameters has been analyzed in ArcGIS environment and classified based on suitable weightage criteria in the study.

B.1 Weighted Overlay Method: After the weightage of each main parameter has been determined, the weightage for the sub class of main parameters have been assigned. All the thematic maps are converted into raster format and

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superimposed one above the other using weighted overlay method with appropriate ranks and weightages through GIS (Fig.7a & b). Integration of thematic maps for carrying out multi-criteria or overlay analysis in GIS environment was done using ArcGIS software (Shivaji Govind and Nitin Mahadeo, 2014). The analyses are performed on seven parameters such as lithology, geomorphology, drainage density, lineament density, soil, slope and land use/ land cover (Manjunatha et al, 2019). The Output resulted map been classified into five categories of viz., very poor, poor, moderate, suitable and highly suitable based on standard deviation classification scheme (Malay Kumar, 2016; Manjunatha et al, 2019).

Table.3. Inter-relationship between the factors concerning Groundwater recharge zones

Sl No	Considered factors	Major impacts	Minor impacts
1.	Lithology	Drainage Density, Slope, Soil, Lineament Density	---
2.	Geomorphology	LULC	Drainage Density, Soil
3.	Drainage Density	LULC	Lineament Density
4.	Lineament Density	Drainage Density, LULC	---
5.	Soil types	LULC	---
6.	Slope categories	Lithology	LULC, Geomorphology
7.	LULC	Drainage Density, Geomorphology	Lineament Density, Soil, Slope, Lithology

Table.4. Continuous Rating Scale of Saaty's Analytical Hierarchy Process

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely
Less Important ←				Equal	→ More Important			
Source: Saaty (1980)								
Note: 1/8, 1/6, 1/4, 1/2, 2, 4, 6, 8 can also be used if more number of classes exists								

Table.5. Different weightage assigned to layers through Analytical Hierarchy Process

Sl. No	Weightage analysis	Lithology	Geomorphology	Drainage Density	Lineament Density	Soil	Slope	LU/LC
1.	Lithology	1	1	4	2	3	1	5
2.	Geomorphology	1	1	4	2	3	1	5
3.	Drainage Density	0.25	0.25	1	0.333	0.5	0.25	3
4.	Lineament Density	0.5	0.5	3	1	3	0.5	1
5.	Soil types	0.333	0.333	2	0.333	1	0.333	3
6.	Slope categories	1	1	4	2	3	1	5
7.	LU/LC	0.2	0.2	0.333	1	0.333	0.2	1
	Column sum	**4.283**	**4.283**	**18.333**	**8.666**	**13.833**	**4.283**	**23**
Consistency ratio (CR) = 0.05 < 1								

Table.6. Percentage of Influencing factor based on Saaty's Analytical Heirarchy Process (AHP)

Sl. No	Influencing Factor	Saaty's Scale (in fraction)	Saaty's Scale (in decimal)	Percentage influence = (Saaty's Scale/sum X 100	Relative Influencing Factor
1.	Lithology	1	1.00	23.36	23
2.	Geomorphology	1	1.00	23.36	23
3.	Drainage Density	1/4	0.25	5.84	6
4.	Lineament Density	1/2	0.50	11.68	12
5.	Soil types	1/3	0.33	7.71	8
6.	Slope categories	1	1.00	23.36	23
7.	LU/LC	1/5	0.20	4.67	5
			Sum =4.28		

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Table.7. Assigned weight according to Saaty's Analytical Hierarchy Process

Sl. No	Influencing Factor	Class Intervals or features	Saaty's Scale (Fraction)	Saaty's Scale (Decimal)	Percentage Influence = (Saaty's Scale/Sum) * 100	Relative Influencing Factor
1.	Lithology	Amphibolite Metapelitic Schist	1/2	0.5	10.141	10
		Migmatite and Granodiorite	1/2	0.5	10.141	10
				Sum = 1.0		
2.	Geomorphology	Channel island	1/4	0.25	2.765	2
		Inselberg	1/3	0.33	3.650	4
		Pediment	1	1.00	11.060	11
		Pediment inselberg complex	1	1.00	11.060	11
		Pediplain moderate	1	1.00	11.060	11
		Pediplain moderate under canal command	1	1.00	11.060	11
		Pediplain shallow	1	1.00	11.060	11
		Pediplain shallow under canal command	1	1.00	11.060	11
		River/ stream	1/5	0.20	2.210	2
		Valley fill shallow	1/4	0.25	2.765	3
				Sum = 7.03		
3.	Drainage Density (m/m^2)	0 – 0.31	1	1.00	43.86	44
		0.31 – 0.60	1/2	0.50	21.93	22
		0.60 – 0.82	1/3	0.33	14.47	14
		0.82 – 0.99	1/4	0.25	10.96	11
		0.99 – 1.32	1/5	0.20	8.77	9
				Sum = 2.28		
4.	Lineament Density (m/m^2)	0 – 0.09	1/5	0.20	8.77	9
		0.09 – 0.19	1/4	0.25	10.96	11
		0.19 – 0.29	1/3	0.33	14.47	14
		0.29 – 0.38	1/2	0.50	21.93	22
		0.38 – 0.64	1	1.00	43.86	44
				Sum = 2.28		
5.	Soil types	Clayey	1/2	0.50	15.24	15
		Clayey-skeletal	1/4	0.25	7.62	8
		Rocky land	1/5	0.20	6.01	6
				Sum = 0.95		
6.	Slope categories	00 – 30	1	1.00	43.86	44
		30 – 70	1/2	0.50	21.93	22
		70 - 110	1/3	0.33	14.47	14
		110 – 180	1/4	0.25	10.96	11
		180 – 400	1/5	0.20	8.77	9
				Sum = 2.28		
7.	Land Use/ Land Cover	Agricultural land	1/2	0.50	43.86	44
		Built-up land	1/4	0.25	21.93	22
		Forest cover	1/3	0.33	14.47	14
		Wasteland categories	1	1.00	10.96	11
		Water bodies	1/5	0.20	8.77	9
				Sum = 2.28		

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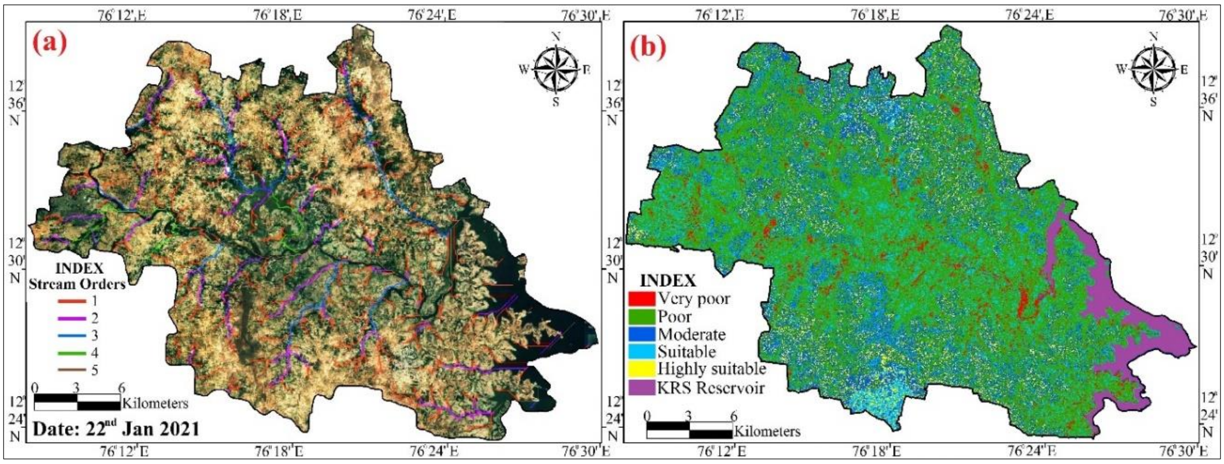

Fig.7: (a) Stream Orders overlaid on Google Earth Image and (b) Overlay Weightage map K.R Nagara taluk

C. Suggested ARS implementation for groundwater augmentation

C.1 Check Dams: Check dams are of greater importance as it addresses water conservation as well as soil erosion. It should be located in the area, which has a higher potential for crop production and settlement areas to allocate the harvested water (Pravat Kumar et al, 2019). Check dams are constructed across 1^{st} or 2^{nd} order streams in areas having gentler slopes (Fig.8). These structures stores water is mostly in confined to stream course with height less than 2mts. Series of such dams are required to be constructed to harness water in a larger area.

C.2 Farm Ponds: Farm ponds are basically small size rectangular trenches will collect run-off water in agricultural fields. These are ideal for the locations of narrow streams with ground on either side with less than 10% of ground slope (Fig.8). The infiltration rate of the soil should be moderate with either barren or shrub type of land use pattern (Manjunatha et al, 2019). The pond should be located above the irrigated fields where it could serve major purposes for irrigation (Manjunatha et al, 2019). This is one of the particular structures that facilitate the recharge of groundwater even after the monsoon season. Interconnectivity of farm ponds could not only result in effective groundwater recharge but also dilute the contaminants in groundwater.

C.3 Nalah bunds: Nalah bunds are small earthen dam which acts as mini percolation tank. Nalah bunds are normally 10 to 15 m long, 1 to 3 m wide and 2 to 3 m high, generally constructed in a trapezoidal form. The Nala bunds should be preferable located in area where contour or graded bunding of lands have been carried out (ARS Manual, 2007). As compared to gully plugs, which are normally constructed across 1^{st} order streams, nalah bunds are best suited across bigger streams and in areas having gentler slopes (ARS Manual, 2007). The rainfall conditions should be less than 1000mm annually in the catchment areas and the soil in bund downstream should prone to water logging (CGWB, 2012).

C.4 Percolation tanks: These are the most prevalent structures in India to recharge the groundwater reservoir both in alluvial as well as hard rock formations (ARS Guide, 2000). It is an artificially constructed surface water body over a permeable land parallel to streams so that the runoff is made to percolate and recharge the groundwater storage (Tarun Kumar and Jhariya, 2016). The hydrogeological condition of sites are of utmost importance along with adequate catchment area where the accumulated water should percolate quickly with least evaporation lose. These structures are built mainly to impound monsoon runoff over a large area where moderate to high porosity of soil and/ or underlying rocky strata are observed. These tanks are more suited across the small streams of lower elevations of 3^0-7^0 (Bhatt et al, 2012).

C.5 Recharges pits/ shafts: It is the most efficient and cost effective structures to recharge the aquifer directly in the areas where source of water is available either for some time or perennially e.g., base flow, springs etc (ARS Guide, 2000). For effective recharge of the aquifers, less permeable zones are required to be penetrated so that the aquifer zones can receive recharge. Recharge pits overcome the difficulty of artificial recharge of phreatic aquifer from surface water sources. Recharge pit is excavated sufficiently deep to penetrate less permeable strata. In recharge pit, water does not directly allowed to mix at water table but infiltrated through the vadose zone. Recharge shaft is also a most efficient and cost effective technique to recharge unconfined aquifer overlain poorly permeable strata and may be dug manually if the strata is of non-caving nature. The diameter of shaft is normally more than 2m.

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C.6 Village tanks modification: Most of the existing village tanks in the study area are often silted up or damaged. These tanks can be modified to serve as recharge structure by desilting its bed and providing a Cut-off trench on the upstream end of the bund for enhancing groundwater recharge.

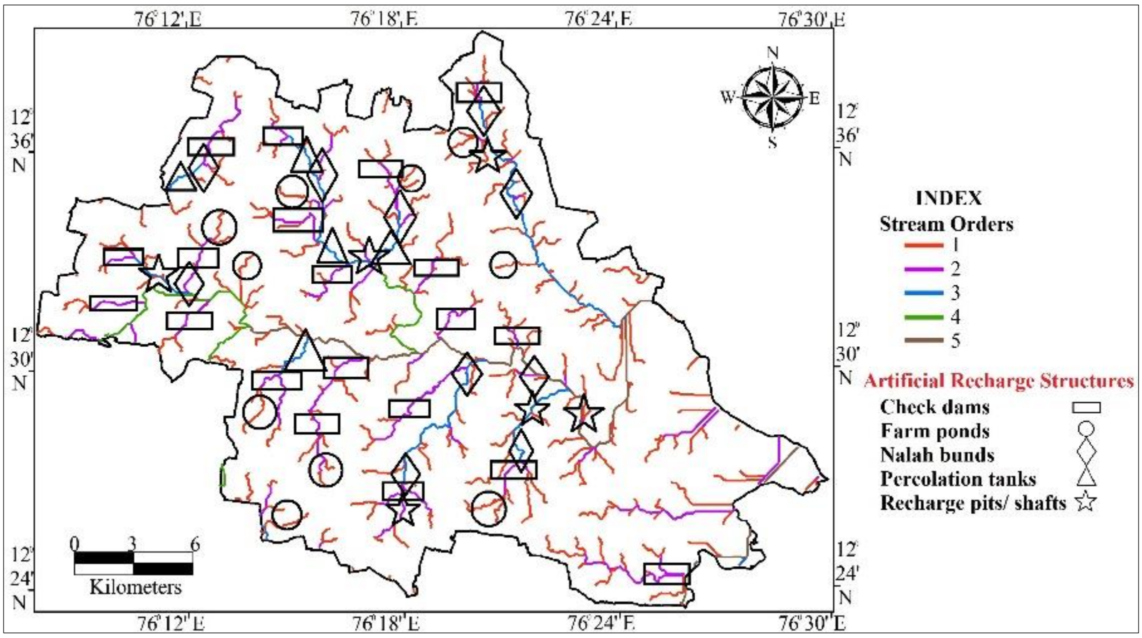

Fig.8: Final Output map for ARS implementation for K.R Nagara taluk

IV. DISCUSSION

Hilly regions of Kodagu is the major catchment area for KRS that serves as water for both drinking and agricultural activities. Scanty rainfall in these region is a bad news for the residents of Mysuru, Mandya and Bengaluru city. With the Cauvery catchment area receiving lesser rains, the water level at Krishna Raja Sagar reservoir is below 100 feet for the third time in the decade, as on 31st July 2016. The water levels hits rock bottom at KRS in September-2016 resembling more of a rocky terrain in the dry districts of North Karnataka rather than a reservoir (Fig.9a & b). This situation was the first time since 1969 that expanses of the terrain especially on the eastern and western side of the reservoir have become visible. The nearly empty reservoir have gone bone dry due to lack of rains during the southwest monsoon and reaching lowest depth of 77.23 ft (against 124.80 ft) during November-2016 which was three feet away from dead storage. Excess water was released from Hemavathi and Harangi into Cauvery River leading to KRS to improve the levels at the mighty reservoir.

Going by the statistics from last four-and-a-half decades, it is predicted that the dam may gradually deplete every upcoming years. Stating that the present water level in KRS will not sufficient to supply drinking water to Bengaluru, Mysuru, Mandya and other towns and villages in the Cauvery Basin. Poor rains in the Cauvery catchment basin was the main reason for the low storage of water in dam. It is very difficult to release water in the canal networks for irrigation purpose especially during hot summers, if the low-yield of rainfall continues. Then the storage water can be maintained only for drinking water needs rather than others.

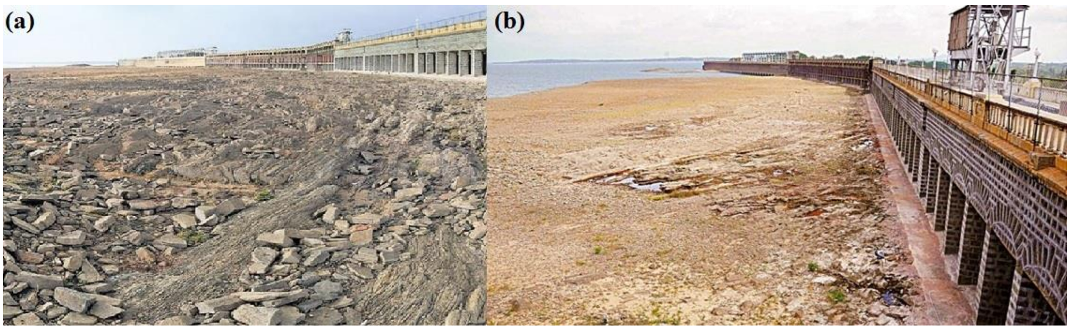

Fig.9: (a) Rocky terrain and (b) Rock bottom in Upstreams of KRS dam

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V. CONCLUSION

The integrated Remote Sensing and GIS along with the AHP technique have proven to be a powerful and more efficient tool for groundwater augmentation and its implement strategies. Satellite data, topographic maps are used to prepare various thematic maps and appropriate weightages have assigned using Analytical Hierarchical Process (AHP). The present study is a model for water planners and policymakers which serves as a water management tool. Implementation of these practices are very much required as it improve natural groundwater recharge and its management for future use. Scope of groundwater development is possible through the construction of suitable recharge structures for groundwater augmentation in Cauvery basin.

Conflicts of interest: The authors declare no conflicts of interest.

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