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Geospatial Perspective for Innovative Planning and Management of Watershed

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Abstract

Innovative watershed management is intense to unravelling watershed related problems on a sustainable manner. Planning and managing developmental practices in the watershed on a sustainable basis usually integrate water or land and both in the present in such a way to attain its goal in the future also. The water-related problems in rain-fed agriculture are often related to high intensity and short duration rainfall, with large spatial and temporal variability, rather than to the low cumulative amount of rainfall. For the innovative planning and Management in the watershed, analysing land degradation through the prioritisation watersheds, assessing the surface runoff, evaluating the Spatio-temporal distribution of the hydrological constraints, groundwater potential zone delineations and the suitable sites for the Rainwater Harvesting (RWH) are considered by spatial multi-criteria evaluation from the several thematic layers that are determined from the remote sensing and GIS technologies. These innovative spatial technologies contribute to reducing vulnerability to climate change and help minimise or even reverse land degradation. The sustainable RWH will improve the surface and ground water level, this in turn improve the economy of the watershed.

Keywords: Geospatial; Innovations; Watershed; Rainfed agriculture; Prioritisation; Groundwater

1. Introduction

Innovative watershed management is intense to unravelling watershed related problems on a sustainable manner. Planning and managing developmental practices in the watershed on a sustainable basis usually integrate water or land and both in the present in such a way to attain its goal in the future also (Said et al. 2006)[(1)]. It includes the land and water resources development plan for enhancing the existing resource to a sustainable and resource action plan for the maintaining the resources from deterioration for the economic expansion in a watershed. The environmental constraints feasible through the implementation of integrated watershed planning and management in an innovative scientific approach (Said et al. 2006; Chowdary et al. 2009)[(1,2)]. The water-related problems in rain-fed agriculture are often related to high intensity and short duration rainfall, with large spatial and temporal variability, rather than to the low cumulative amount of rainfall (Ibrahim-Bathis and Ahmed, 2016a) [3]. It has been increasingly recognised that in areas where agriculture is constrained by poor rainfall distribution in time and space, innovations that increase rainwater use efficiency and water management strategies have great potential to improve food security and livelihoods (Ibrahim-Bathis and Ahmed, 2016b) [4]. For the innovative planning and Management in the watershed, analysing land degradation through the prioritisation watersheds, assessing the surface runoff, evaluating the Spatio-temporal distribution of the hydrological constraints, groundwater potential zone delineations and the suitable sites for the Rainwater Harvesting (RWH) are considered by spatial multi-criteria evaluation from the several thematic layers that are determined from the remote sensing and GIS technologies (Ibrahim-Bathis and Ahmed, 2014) [5]. Geospatial science including the Remote sensing technique affords treasured and reliable spatial information on land and water resources (Chowdary et al. 2009; Ibrahim-Bathis and Ahmed, 2016a) [2,3]. Geographical Information System (GIS) with its proficiency of integrating and analysing the multi-layered spatial information to be an effective tool in the innovative planning for watershed development (Ibrahim-Bathis and Ahmed, 2016b) [4]. These innovative spatial technologies contribute to reducing vulnerability to climate change and help minimise or even reverse land degradation**.**

2. Prioritisation of Sub-Watershed

The planning and management programs for sustainable development in the watershed, inventory on quantitative soil erosion loss and the priority classification of sub-watershed are essential (Ibrahim-Bathis and Ahmed, 2013) [6]. The priority classification of the watershed can help in taking up soil conservation measures on a priority basis. The morphometric parameters which influence the soil erodibility are considered to prioritise the sub-watershed (Biswas et al.1999) [7]. It includes the linear parameters such as mean bifurcation ratio (Rbm), drainage density (Dd), texture ratio (T), length of overland flow (Lo), stream frequency (Fs), and the shape factors are compactness constant (Cc), circularity ratio (Rc), elongation ratio (Re) and form factor (Ff). CartoDEM (1 arc second) was used to extract the drainages and delineate the watershed using Arc hydro Tool in the ArcGIS domain. The morphometric parameters were calculated using the standard formula from the literature (Ahmed et al. 2010; Ibrahim-Bathis and Ahmed, 2014) [5,8]]. The higher the drainage density (Dd), the more possibilities of erosion there are (Figure 1). Form factor (Ff) describes the shape of the watershed. The shape of the watershed is also responsible for the movement of silt. The more elongated the watershed, the lower the possibility of silt load reaching to the outlet. The ranking of the watersheds has been carried out for giving the highest priority/rank based on highest value for linear parameters and lowest value for shape parameters (Ibrahim-Bathis and Ahmed, 2013) [6]. After the rating has been assigned based on every single parameter, the rating value for all the 24 sub-watersheds was averaged so as to arrive at a compound value (Table 1 and Figure 2). Compound value for sub-watersheds was used to prioritise on the basis of their severity for soil erosion; the lowest compound value has been given very high priority, and highest value has been given low priority (Ibrahim-Bathis and Ahmed, 2013) [6]. The morphometric analysis can be used for prioritisation of sub-watershed even without the availability of reliable soil maps of the study area (Biswas et al. 1999) [7]. The measurement and the implementation of the action plan to conserve and regulate the land from the soil degradation can be assessed on a priority basis.

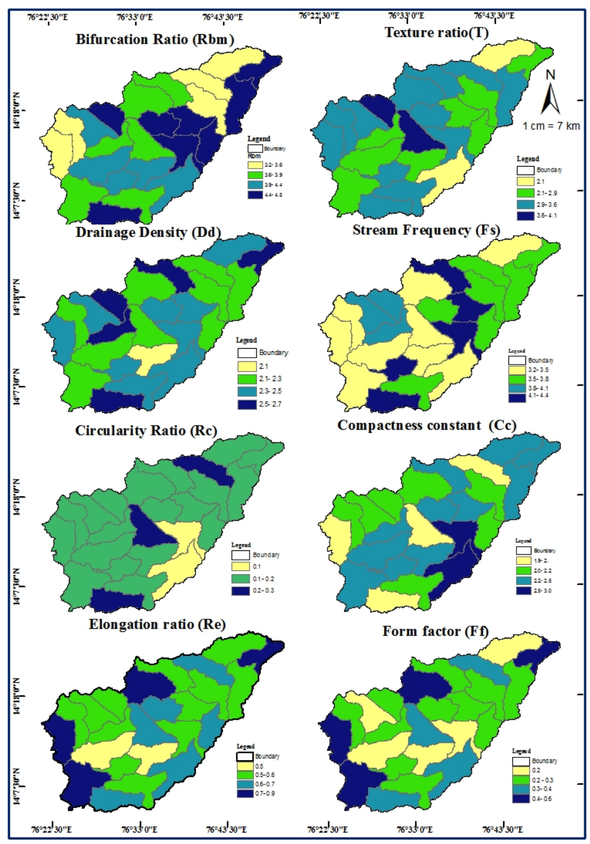

Fig. 1. Morphometric parameters of sub-watershed in the Doddahalla watershed

Table 1. Ranking of morphometric parameters and prioritisation of sub-watersheds

Sl no	Name of S/W	Rbm	Dd	Fs	T	Ff	Re	Rc	Cc	Lo	Total	Cp#	Rank*
1	Bommasandra	22	16	20	17	23	22	9	16	16	161	17.9	L
2	Challakere_north	12	21	18	22	2	2	6	19	21	123	13.7	M
3	Chikkenahalli	9	3	8	1	9	8	16	10	3	67	7.4	VH
4	Durgavara	18	24	24	21	1	1	12	12	24	137	15.2	L
5	Ganjigunte	1	7	19	23	19	18	1	24	7	119	13.2	M
6	Garanihalla	3	13	1	15	11	10	4	21	13	91	10.1	H
7	Gollanakatte	11	11	21	24	4	3	8	17	11	110	12.2	M
8	Gonuru	20	5	14	16	24	23	10	15	5	132	14.7	M
9	Govinalu Lower	17	14	7	4	5	4	13	11	14	89	9.9	H
10	Govinalu upper	13	1	6	20	8	7	5	20	1	81	9	VH
11	Himampura	16	23	17	2	20	19	21	3	23	144	16	L
12	Hosaramjogihalli	7	8	2	6	3	3	2	23	8	62	6.9	VH
13	Hotteppanahalli	6	17	15	18	15	14	15	8	17	125	13.9	M
14	Karabayyanahalli	14	22	22	3	21	20	18	6	22	148	16.4	L
15	Kasipura	15	4	3	7	7	6	3	22	4	71	7.9	VH
16	Kyatagondanahalli	4	15	11	10	13	12	7	18	15	105	11.7	H
17	Lambadihatti	2	18	13	19	14	13	14	9	18	120	13.3	M
18	Laxmipura	5	19	10	5	18	17	23	1	19	117	13	M
19	Lingarhatti left	8	6	5	11	6	5	12	13	6	72	8	VH
20	Lingarhatti right	3	2	4	8	17	16	22	2	2	76	8.4	VH
21	Maradidevagere	3	12	12	12	12	11	17	7	12	98	10.9	H
22	Medihalli	21	10	16	9	22	21	20	4	10	133	14.8	M
23	Ullarti	19	20	23	13	10	9	19	5	20	138	15.3	low
24	Upparahatti	10	9	9	14	16	15	11	14	9	107	11.9	H

*** <6 to > 9 = Very High, <9 to > 12=High, <12 to >15= Medium, and <15 to >18= Low. # compound value**

Table 2. Soil infiltration rate (Brouwer et al. 1988; Ibrahim-bathis and Ahmed 2016a) [3,9]

Sl No	Soil texture	Infiltration rate mm/hr
1	Gravelly Loamy Sand	30
2	Sandy Loam	20-30
3	Loamy Sand	15-20
4	Sandy Clay Loam	Oct-15
5	Silty Clay Loam	7.5-10
6	Clay Loam	05-Oct
7	Clay	01-May

3. Spatio - Temporal Variability of Infiltration Pattern

The present research investigated the hydrogeological determinants to assess the sensitivity of each factor to the infiltration pattern in the Doddahalla watershed. Infiltration is the water penetration into the soil and subsurface layer from the precipitation or by snowfall. Infiltration are soil hydraulic properties that direct the access of water to the soil and its successive vertical movement or storage in the subsurface (Omuto and Gumbe 2009; Zhao et al. 2013) [10,11]. Infiltration is a key important in agriculture and water research because of its necessary role agricultural irrigation, land-surface and subsurface hydrology (Zouheira et al. 2015) [12,13]. Designing the efficient irrigation systems for the sustainable agriculture in the arid and semi-arid region requires the prior knowledge of the infiltration characteristics of soil (Machiwal et al. 2006; Pedretti et al. 2011; Ibrahim-bathis and Ahmed, 2016a) [3,14,15] is varied spatially and temporally. Dry soils infiltrate more rapidly, and eventually it reaches a steady rate

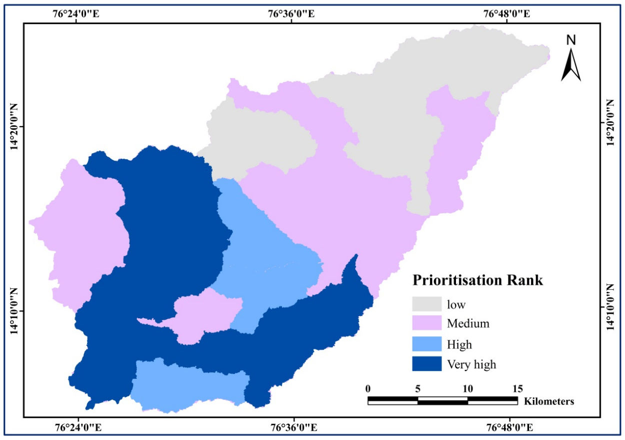

Fig. 2. Prioritisation of sub-watershed in the Doddahalla watershed

when all the air pores in the soil layer are filled with the water. Quantitative measurement of the rate of soil infiltration in a watershed is difficult because it depends on many factors such as soil texture, surface topography, the intensity of rainfall and vegetation cover (Brouwer et al. 1988; Zouheira et al. 2015) [13] also get flourished (Ma et al. 2010; Nampak et al; Zouheira et al. 2015) [12,13,16].

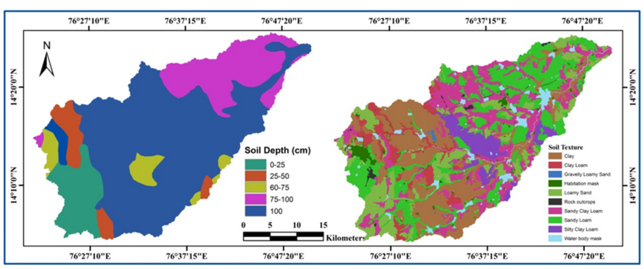

Fig. 3. Soil depth and Soil texture map of Doddahalla watershed

Soils texture and depth

The area had blessed by nature with fertile black soil rich in bases and having water holding capacity. The black soils found in a wide area in the watershed are particular suited for rainfed crops like short-staple cotton, groundnut, jowar and tur dhal. Soils in the region are found to contain a high concentration of soluble salts that are either critical for growth or critical for germination. Clay, sandy clay and silt clay are major soils and food crop are the major agricultural practice. Soil map can be prepared using the high-resolution satellite images and along with extensive field data (Ismail and Yacoub, 2012; Ibrahim-bathis and Ahmed, 2016a) [3,17]. Available secondary map from the National Bureau of Soil Survey and Land Use Planning (NBSS and LUP) Bangalore and satellite images are used to the map the soil types of the area (Figure 3). Clay, sandy loam and sandy clay loam together covers 70% of the total land area. The soil depth varies from 25 cm to 100cm (Figure 3). The gravelly sand soils possess more open spaces to fill the water than the compact clay or silt soils. The dry clay soil exhibits multiple cracks in the top layer that enhance the rapid infiltration. However, the wet clay soil has more water holding capacity than the infiltration rate (Table 2). Infiltration variability in the area is evaluated by incorporating the highly impacting factors according to their characteristic and interrelationship with infiltration depth (Table 3 and Figure 4). The soil infiltration map was prepared from the quantitative soil measurement calculated from Soil Conservation Service-Curve number (SCS-CN) loss model in the Hydrologic Engineering Center- Hydrologic Modeling System (HEC-HMS) (Figure 5 and Table 2) and cross-validated with the secondary published data (Brouwer et al. 1988; Ibrahim-bathis and Ahmed, 2016b) [4,9]. This infiltration variability map is useful for studying irrigation requirements in the region, and the measure can be initiated to increase the infiltration potentiality in the area by proper management practices.

4. Geospatial technologies for delineating Groundwater potential zones

Groundwater, or subsurface water, is a term used to denote all the waters found beneath the ground surface. It is one of the most significant natural resources worldwide serving as a primary source of water for communities for domestic purpose, industries, agricultural productions (Pradhan, 2009; Ayazi et al. 2010; Manap et al. 2012; Ibrahim-bathis and Ahmed, 2016a) [3,18–20], and for tourist developments (Jaturon Konkul et al. 2014) [21]. Groundwater is naturally replenished by rain or snow melts which seep down through the soil and/or through pore spaces of underlying rocks (Nampak et al. 2014) [16]. Hence, its occurrence and distribution depend on the climate and regional setting of the region, surface and subsurface characteristics such as fractures in the underlying rock, land use type, geomorphic features, structural features and their interrelationships with the hydrological characteristics (Jaturon Konkul et al. 2014) [21]. Groundwater demand is drastically increasing due to the immense pressure on population and urbanisation, global impact due to climate and weather change, repetitive drought condition and lack of rainfall. Over exploitation of the groundwater resource caused a sudden decline in the groundwater table and an excess in the sustainability of groundwater resources (Jaturon Konkul et al. 2014; Ibrahim-bathis and Ahmed, 2016a) [3,21]. Especially the agrarian states like Karnataka, the groundwater dependence is high. Recent studies indicate that 26 % of the area of Karnataka state is under over exploited category and numbers of villages are under the critical category (Central Ground Water Board, 2013) [22]. The complexity of conventional exploration methods such as field-based hydrogeological, geophysical resistivity surveys, exploratory drilling which is more time-consuming and very expensive, supports the application of satellite-based Geospatial Science. Hydrologists have utilised the Geospatial technology for the groundwater mapping by integrating thematic maps such as geomorphology, drainage pattern, lineament, soil, rainfall intensity and soil texture, resistivity, aquifer thickness, or fault maps (Chowdary et al. 2009; Nampak et al. 2014) [2,16]. The groundwater prospective zone mapping was carried out by integrating the thematic maps such Land use land cover, Geomorphology, Soil texture and depth, Slope, Lineament, Drainage and Rainfall maps in a spatial domain of GIS environment. Cartosat-1 DEM (30m), Landsat 8 Operational Land Imager (OLI -30m), Survey of India (SOI) toposheets (57 B/7, 57 B/8, 57 B/11, 57 B/12, 57 B/15 and57 B/16) and High resolution satellite images from Google Earth (Digital Globe, Astrium and SPOT) were used for preparation of thematic maps.

Land use Land cover map (LULC)

Land use type gives the necessary information on infiltration, soil moisture, groundwater, surface water, etc. the land cover classes representing Forest, Kharif cropland, Rabi cropland, double crop land, built up/barren, and water bodies gave the weight with respect to the groundwater availability (Figure 4). Forest vegetation and agricultural cropland possess more cracks in the soil and loosen the compactness of the soil that intern accelerates the infiltration rate in the soil (Table 2). Cropland covers only 60 % of the total land area. Nearly 50% of the agriculture land is Kharif crop (Figure 4). The high weight is assigned to the forest plantation, agricultural plantation and double crop land. The low weight assigned to the seasonal crops and fallow land (Table 3).

Rainfall

Rainfall is the most dominant influencing factor in the groundwater potentiality of any area and is the major water source in the hydrological cycle. Annual rainfall data is collected from the rain gauging stations of the Indian Meteorological station (IMD). The study area has a limited number of rain gauge stations hence the telemetric stations are also used to determine the average annual rainfall in the area. The rainfall map prepared by employing an Inverse Distance Weightage (IDW) interpolation method in ArcGIS. The annual rainfall ranged from 288 mm to 739 mm and grouped into five categories (Figure 4). Intensity and duration of rainfall play a significant role in the infiltration. High intensity and short duration rain possess less infiltration and more surface runoff. Low intensity and long duration rain possess high infiltration than the runoff. High is weight is given to the high rainfall area and least weight given to low rainfall area (Table 3). More than 50% of the total land area receives only 578 mm average annual rainfall.

Table 3. Criteria for each thematic layer (Ibrahim-bathis and Ahmed, 2016a) [3]

Thematic class	Weightage*	Thematic class	Weightage*
LULC Class		**Soil texture**	
Forest	5	Clay	1
Kharif + Rabi (Double Crop)	5	Clay Loam	2
Kharif crop	4	Silty Clay Loam	2
Rabi crop	4	Loamy Sand	3
Built-up land	3	Sandy Clay Loam	3
Water bodies	5	Gravelly Loamy Sand	5
Rainfall (mm)		**Soil Depth (cm)**	
288-394	1	Very shallow (10-25)	1
394-465	2	Shallow (25-50)	2
465-523	3	Moderate Shallow (60-75)	3
523-609	4	Moderate deep (75-100)	4
609-739	5	Deep (>100)	5
Slope in %		**Drainage Density** (Km/Km^2)	
0-1	5	0.26-1.02	5
01-May	3	1.02-2.48	4
May-50	3	2.48-3.97	3
Geomorphology		**Lineament Density** (Km/Km^2)	
Denudational and Structural Hills	1	0.0 - 0.39	1
Pediment - Inselberg Complex	2	0.39 - 0.78	2
Pediplain weathered	3	0.78 - 1.18	3
Valley Fill	4	1.18 – 1.57	4
Pediplain moderately weathered	5	1.57 – 1.97	5

* weight 1 for poor to 5 for very high

Slope

The slope is the rate of change of elevation and is also a significant factor in identifying groundwater potential zones. Increased slope results in high runoff and erosion of surface soil. Gentle and nearly level surface slope allows the water to flow very slowly and provide adequate time to infiltrate into the soil. A high weight is assigned to the nearly level and gentle slope (Table 3). Cartosat DEM of 30-meter spatial resolution image was used to prepare the slope map of the area. Slope map was divided into five classes according to the percentage of their gradient, and the value ranges from 0 to 50% (Figure 4). Zero percentage is near level plain land, and 50 % is very steep slope area. About 90% of the total area is gentle and nearly level land which allows the maximum infiltration than runoff.

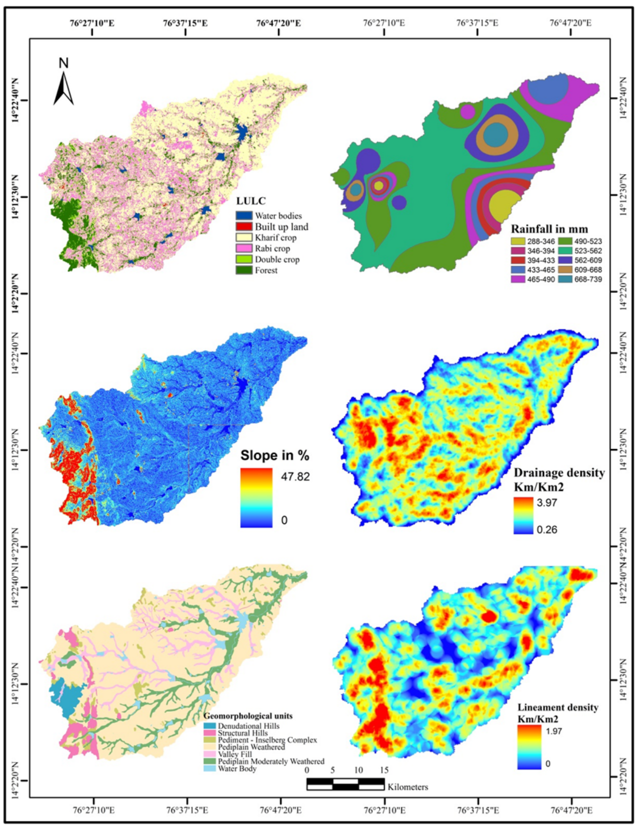

Fig. 4. Thematic maps of Doddahalla watershed

Drainage density

Drainage density is the closeness of spacing of stream channels, and it is the ratio of the total length of the stream segment of all orders per unit area. The drainage density is an inverse function of permeability which plays a vital role in the runoff distribution and level of infiltration. Drainage networks are extracted and delineated from CartoDEM with the help of Arc Hydro tool 9.3 for ArcGIS (Ibrahim-bathis and Ahmed, 2013) [6]. Extracted drainages are updated both from Landsat 8 data and real-time Google Earth images. Delineated drainages overlaid on the digitised streams from SOI topo map, which shows almost similar patterns. Drainage density map prepared using the line density analysis tool in ArcGIS software (Figure 4). The value ranges from 0.26 to 3.97 km/km^2 (Sreedevi et al. 2009) [23]. Drainage density is inversely related to the soil infiltration capacity; high weight is given to low density, and high density is assigned less weight (Table 3).

Lineament density

Lineaments are the most prominent structural features that are important from the groundwater point of view (Pradhan, 2009) [18]. They appear as linear alignments of structural, lithological, topographical and drainage anomalies, etc. as straight lines or as curvilinear features. Lineament map was prepared from the drainage network and visual interpretation of false-color Landsat 8 image (Teikeu Assatse et al. 2016) [24]. Google Earth images are utilised to cross-check the linear feature in the image where field data are limited. The density of these linear features ranges from 0.0 to 1.97 km/km^2 (Figure 4). An area having the high lineament density is considered as high groundwater zone (Table 3).

Geomorphology

The major geomorphic feature initially digitised from the toposheet, and the minor feature is then updated from the satellite images and the Cartosat DEM image. The differences in elevation, contour lines, and types of vegetation given a clue to map the geomorphological features. The available secondary data and high-resolution satellite images from the Google Earth are used to classify micro features. The area is nearly plain and shows gentle slope from south-west to northeast. Elevated hills saw only in the extreme south-west region of the watershed (Figure 4). A shallow weathered plain covers more than 60% of the total land area. A high weight is assigned to the low-lying weathered geomorphological unit and low weight to the highly elevated hard rock hillock (Table 3).

Each thematic map classified into different subclasses and each is assigned a weight value according to the interrelationships between the occurrences of groundwater (Table 3). After assigning weights to the individual class in each theme, the whole thematic layer is integrated into a single layer in ArcGIS software. The aggregate weight value of each sub-class in the integrated layer is categorised into five individual groups as groundwater prospect zones (Figure 6). The high weight value is categorised as the very good prospect zone and the least weight values as the poor prospect zone. Very less area identified as the rich in groundwater resource. More than 70 percentage of the total land area categorised moderate to poor groundwater resource. Groundwater potential map provides the preliminary information on the groundwater resources of the area. The depth of groundwater level changes through the seasons and in the monsoon and post monsoon period the groundwater depth is nearly 5 to 10 meter below ground level in most places according to the Central Ground Water Board (CGWB) report.

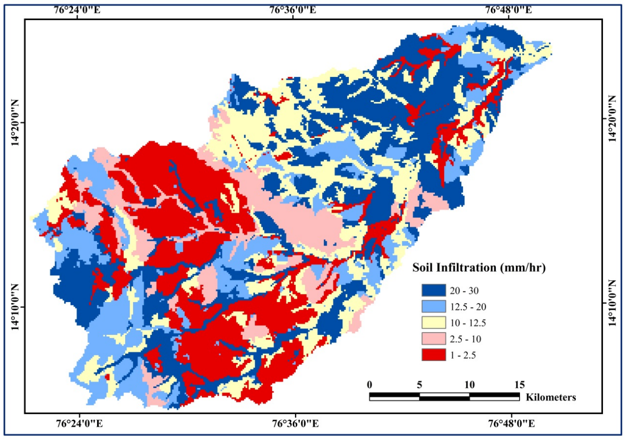

Fig. 5. Soil infiltration variability map of Doddahalla watershed

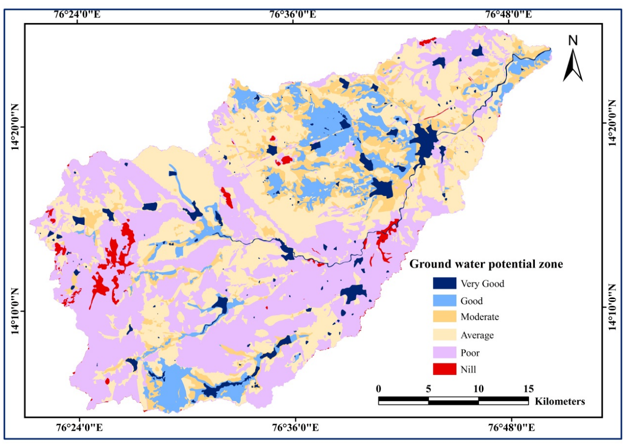

Fig. 6. Groundwater Potential zone map of Doddahalla watershed (Ibrahim-Bathis, K., Ahmed, S.A., 2016a) [3]

5. Rainwater Harvesting (RWH)

The water is the most limiting resource in the arid and semi-arid region where the rainfall is low and highly variable in the inter- and intra-season and often inadequate for the economic progress in agricultural and crop production (Barron et al. 2003; Ziadat et al. 2012; Glendenning et al. 2015) [25–27]. In order to prevent the excess runoff of the storm water that is often lost during the rainy season, rainwater harvesting (RWH) is an efficient approach in the semi-arid and arid regions. The rapid urbanisation and drastic growth in the population density in the developing countries like India RWH and conservation is increasingly recognized as critical effort to attainment the economic and financial sustainability, to overcome the uneven water supplies and avoiding the drinking and irrigation water scarcity (Shah, 1998; Sekar and Randhir, 2007; Ziadat et al. 2012; Yousif et al. 2015) [26,28,29]. The RWH imply the watershed to retain the rainwater and consent delay in the transfer of surface runoff into groundwater, evaporation and transpiration. This process of transfer of blue water (rivers and aquifers) into green water (soil water and plant water use) impact and change the hydrological balance of a watershed by the potential increase in the available surface and groundwater resources (Glendenning et al. 2015) [27]. This sustainability would improve the socio-economic and financial status through agricultural crop production and other domestic practices engaged in the watershed. Though the RWH is beneficial to the developmental purpose of the watershed, the poor selection of suitable sites and efficient structure causes the major reason for the failure of RWH projects and the slow adoption of rainwater harvesting techniques in many parts of the world (Oweis et al. 1998; Ziadat et al. 2012; Yousif et al. 2015; Glendenning et al. 2015) [26,27,30,31]. Hence, the RWH technology is worthwhile when it is approached through the Geospatial science. The advance and modern space sensor derived satellite images could afford the best selection of the RWH sites and the Geographical Information System (GIS) oriented Decision support system (DSS) enhances the convenient structure for the RWH in the watershed. Several aspects of the terrain and climatic variable, as well as socio-economic facet, have to investigate prior to the implementation of any RWH projects. This includes the land use and land cover feature, topography, rainfall and distance to the human settlement and the utility systems (Glendenning et al. 2015) [27]. The amount and the intensity of the rainfall is a key criterion for the RWH. Soil depth and texture govern the amount of water can store in the soil profile. Green vegetation and stoniness are indicators of the potentiality of land to sustenance rainwater harvesting. The RWH has multiple benefits to agriculture and other domestic uses and merely is a challenge in many regions because of the variability in precipitation in semi-arid regions (Ziadat et al. 2012; Yousif et al. 2015) [26,31]. The RWH is essential for the water resources sustainability and to overcome the inadequacy of waters demands, to increase infiltration and enhance groundwater quality in the water scarce region. To increase agriculture production and to improve the ecology of the area by an increase in vegetation cover RWH is ultimate choice in the watershed. The RWH has also reduced flood hazards and mitigates the effects of drought. The RWH reduces soil erosion and storm runoff in a terrain and steep topography.

Most of the developed and developing countries in the world follow the strict laws and rules for the RWH to minimise the water crises. In India, RWH is dates backs to the pioneer civilisation. The tank system is traditionally the backbone of agricultural production in arid and semi-arid areas of India (Glendenning et al. 2015) [27]. The importance of harvesting and conservation is earnestly coated in the all the religion, and they treated as the sacred place. The present decade the roof top RWH method was made compulsory for every new building to avoid groundwater depletion in the country. Tamil Nadu state took it as role model and given excellent results in its implementation and recorded the rise in water level and significantly improved the water quality. The Doddahalla watershed is water scarce semi-arid region with frequent drought. The rain is variant and records very little amount in the peak season. The RWH is the vital choice for surface and groundwater sustenance of water resource in the watershed. The agriculture and other allied activities predominantly depend on the rain. Most of the crops grown here is rainfed. There are many success stories in the Thar Desert and especially in the Sub-Saharan Africa (SSA) countries which employed the most advanced RWH technologies for the drought mitigation and over the water scarcity problem. Some of the widespread and important land and water harvesting technology are expressed to implement in the water scarce Doddahalla watershed to over in the water scarce related issues. The best fit water harvesting structures are selected by considering the terrain and climatic favourability of the study area and their implementation sites are suggested through the spatial multi-criteria process using the Geospatial technology (Figure 7).

Check Dams

Check dams are the old method of water harvesting, constructed across small streams with gentle sloping terrain. The site selected should have sufficient thickness of permeable bed or weathered formation to facilitate recharge of stored water within short span of time. The water stored in these structures is mostly confined to stream course and the height is normally less than 2 m and excess water is allowed to flow over the wall. The series of several check dams are constructed at regular interval to recharge on regional scale and prevent sedimentation from the soil erosion. It is the low cost way of harvesting the water and to measure the soil erosion. The method and the material included in the construction forms its classification. The check dams are constructed from locally available boulders in a mesh of steel wires (Gabion structure) and Clay filled cement bags (Nala bunds) are arranged as a wall or a barrier across small streams. Gently sloped areas are best suited for the check dam construction. Vegetative check is small embankments with vegetation used as gully plugging using locally available herbs and shrubby species. Vegetative checks proposed in the first order streams, which reduce the soil erosion due to head, ward erosion. Boulder check are locally available boulders, arranged to stabilize to form a small dam to the vegetation by holding some water and help to improve the ground water resource and to control the soil erosion. The cattle movement coupled with rain action causes movements of soil in the form of sediments and ultimately collected in tanks as silt. This can reduce the storage efficiency of the tank. Desiltation of tanks can be constructed to avoid this siltation and improve the storage capacity of the tanks.

Percolation tank

Percolation tank is a common and an artificially created surface water body, submerging in its reservoir a highly permeable land so that surface runoff is made to percolate and recharge the ground water storage. Usually, Percolation tank may be constructed in the lower orders stream preferably in the second to third order streams. The recharge area downstream should have sufficient number of dug wells and cultivable land to benefit from the augmented groundwater. The size of percolation tank may be of any kind; however, it would be encouraged to decide based on the by percolation capacity of underlying bedrock. The percolation tanks enhance the water recharges into the ground water storage. Measure has to be taken to prevent severe soil erosion through appropriate soil conservation practices in the catchment. This will retain the tank free from siltation which otherwise reduces the percolation efficiency and life of the structure.

Recharge pit

The recharge pit is among the cost effective as well as efficient practices to improve the rainwater recharge. Recharge pit may be dug manually if the strata are of non-caving nature. The diameter of the shaft is normally more than 2 m. These recharge structures are very useful for the study area because shallow clay layer impedes the infiltration of water to the aquifer. It is seen that in the rainy season most of the tanks are fully or partially filled up but water from these tanks does not percolate down due to siltation and tube well and dug wells located nearby remains dried up. The water gets evaporated in the hot condition and is not available for the beneficial use. By constructing recharge pits in these tanks, surplus water can be recharged to groundwater rather allow the surface runoff, ensuring the abundance of sufficient water for domestic use. This can replenish the groundwater and improve the crop production and fulfill the domestic water need in the summer season.

Chauka System

Lapodiya the dry village of 200 households in Jaipur district of the Rajasthan is living example of innovative water conservation practices and mitigated the drought into the safe environment in the desert climate. The villagers created series of interconnected square dykes in the fields to trap enough water for soil productivity and allow excess water to sustained flow neighbouring Chaukas utilizing each drop of rainwater.

Chaukas replenishes the aquifers and also serve as drinking trenches for the village livestock. The village experience the green fodder when the neighbouring village suffered seriously from drought in 2003 and again in 2007. The voluntary participation from the villages is the key to success of the Lapodiya. They are changing the degraded pastureland to rainwater harvest. Similar innovative structures are also found in the Kundla village of Alwar District in Rajasthan. Residents of this village constructing the series of the rectangular water harvesting structure called Talab. The Doddahalla watershed there has many crop lands that remain left fallow for several season due to the failure of the expected rainfall. These structures can employ in such vacant or fallow crop land to promote the groundwater recharge and to sustain the soil water moisture. This intern increases in the agricultural and crop production in the area and possess to overcome most of the water-related issue in the area. The Chaukas or the square shaped embankment system not only retains the rain water also prevent the soil erosion. This system can also effective when it combines with planting of tree in each square.

6. Cropping pattern

The sustainable management of the natural resources in a region is only possible when the available resources are well planned and managed. The executing the ideal and most suitable cropping pattern in an area is an indication of the sustainability planning in the region. The selecting the ideal crop means the crop water requirements has to fulfill with available water through irrigation. This requires the estimation of crop water require and the amount of available water resources. The crop water requirements depend on the type of crop i.e., a fully developed maize crop needs more water per day than a fully developed crop of onions (Ibrahim-Bathis et al. 2021)[(32)]. The duration of the growing period also influences the water need of particular crops i.e. short duration crops require less water than the long duration crops. The daily water need of melons is less than the daily water need of peas, but the seasonal water need of melons is might higher than the beans. The Groundnut, Maize, Ragi, Jowar, Sunflower and Onion are the major crops cultivated in the Doddahalla watershed. The crops require the fertile soil and water. The amount of the water needs and the types of soil is differing from the crops to crop (Ibrahim-Bathis et al. 2021)[(32)].

Groundnut is an important oilseed crop in the study area. The crop can be grown in places receiving a minimum rainfall of 500 mm and a maximum rainfall of 1,250 mm. Groundnut is a rain-fed Kharif crop, being sown from May to June, depending on the monsoon rains. Sandy loam and loamy soils and also black soils are good for this crop. Ragi also known as finger millet is an important cereal, grown in areas with rainfall ranging from 5001000 mm and in the irrigated areas

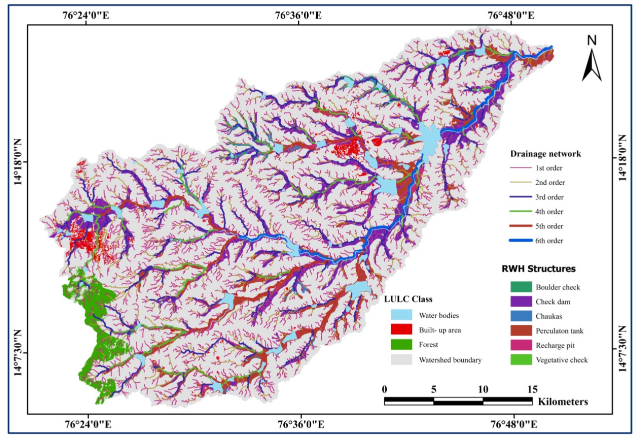

Fig. 7. Site suitability map of RWH in Doddahalla watershed

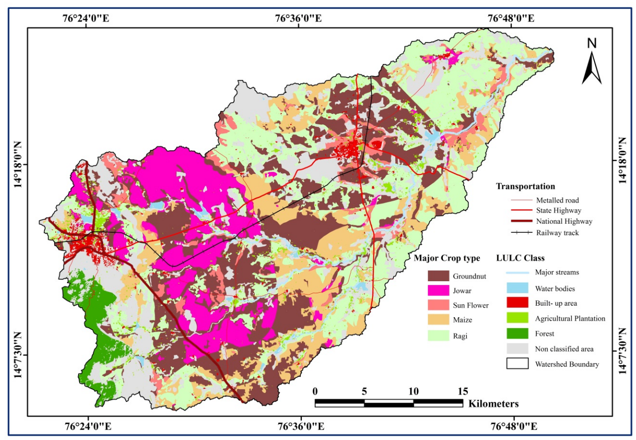

Fig. 8. Proposed major cropping pattern in Doddahalla watershed (Ibrahim-Bathis 2021) [(32)]

of the watershed. The Ragi crop is well suited in red loams, black and sandy loams. The rain fed crop is cultivated both as a Kharif and Rabi crop. Maize is a short duration warm weather crop and grown in any type of soil ranging from well-drained deep heavy clays to light sandy soils. Maize is highly susceptible to salinity and water logging during seedling stage. The soil with high water holding capacity and good drainage is ideally suited for maize cultivation. Jowar is the most important food and fodder crop of dryland agriculture. The Rabi Jowar are wholly confined to black cotton soils, and the Kharif Jowar are grown on light soils. Sunflower is another important oilseed crop requires a cool climate and thrives well in deep and well-drained light soils (Ibrahim-Bathis et al. 2021)[(32)]. It performs well in the black cotton soils Deccan plateau. The multi-layer thematic integration is processed to the select the ideal crops in the watershed considering the soil, rainfall and cropping pattern in the region (Figure 8).

7. Conclusion

The multi criteria analysis provides indigenous knowledge to identify and locate the suitable areas for RWH. The sustainable RWH will improve the surface and ground water level, this in turn improve the economy of the watershed. Sensitivity analysis was conducted prior to assigning weights to influencing factors and locating the suitable areas for RWH in the study. Due to the scarcity of the water resources and poor distribution of rains, the RWH is considered an alternative and viable water supply system, particularly during the dry periods in the Doddahalla watershed.

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