Prioritization of sub-watersheds of the Kanakapura Watershed in the Arkavathi River Basin, Karnataka, India - using Remote sensing and GIS

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ABSTRACT
Prioritization of sub-watersheds is a crucial aspect of watershed management as it may not be possible to execute development programs at a time for entire watersheds in a basin owing to the paucity of financial resources. The present study attempts to prioritize sub-watersheds in the Kanakapura watershed, in Ramanagara district, Karnataka, based on the multi-criteria ranking method. This process involves extraction and determination of various parameters such as rainfall, lithology, drainage density, slope, lineament, hydrogeomorphology, land-use, and land-cover, using information from rain gauges, topographical sheets, and satellite imagery in Geographic Information System (GIS) platform. Kanakapura watershed is subdivided into nine sub-watersheds, namely, Bannimukudlu, Bennagodu, Doddaalahalli, Gadasahalli, Horalagallu, Kodihalli, Madaralahalli, Maraleebekupe, and Mudagod. Priorities indexing of each of the parameters was done, based on their impact significance, and overlay analysis was performed to identify critical sub-watersheds. Some of the strategies proposed for effective conservation and management of water resources are the construction of a check dam, implementation of water harvesting methods, identification of artificial recharge sites. The results of the study show that priority needs to be given to the Bannimukudlu and Kodihalli sub-watersheds followed by remaining sub-watersheds to regulate surface water flow thereby improving water table level.

I. Introduction
Management of water resources continues to be a challenge in developing countries like India. Water resource development calls for addressing critical issues of storage, conservation, and subsequently utilization of surface and subsurface water. Towards evolving a comprehensive management plan for suitable conservation and utilization of available water resources in a country, space technology plays a crucial role. Combining conventional groundwater measurement techniques and remote sensing (RS) methods set the stage for attaining optimum planning and execution of water resource projects. Conventional data can be supplemented by the synoptic and repetitive coverage of satellites to monitor the progress and impact of the aforementioned projects. RS, in combination with Geographical Information System (GIS) produces terrain maps, containing detailed information of the variables under study.

Effective and efficient planning and maintenance of natural resources are the primary concern for sustainable development. The basic units for the management of land and water resources include drainage basins, catchments, and sub-catchments (Moore et al., 1991). Watersheds are natural hydrologic bodies that extend over a finite area of land from which rainwater flows to a defined gully, river, or stream at any specific point (Kumar & Kumar, 2011). Watershed prioritization may be described as the process of identifying environmentally stressed sub-watersheds or pockets, for taking steps for soil conservation on a priority basis. Several scientific criteria based on soil loss, sediment yield, topographic, or morphological factors have been applied individually in the past to identify environmentally stressed sub-watersheds/areas (Pandal et al., 2005; Shrimlai et al., 2001).

In order to achieve sustainable development of watershed, several attempts have been made to rank them based on their priority. Morphometric parameters are the key elements in determining the quantitative estimation of watershed characteristics (Bhattacharya et al., 2019; Biswas et al., 1999; Strahler, 1964). Morphometric analysis requires measurement of three important aspects – linear, aerial, and slope of drainage basin (Nautiyal, 1994). Earlier work was carried out in the Kanakapura watershed on morphometric analysis (Hema and Govindiah 2012) and land-use land-cover mapping (Hema et al., 2012). Based on the distribution of the stream network Kankanapura watershed is divided into nine sub-watersheds. Land use and land cover (LULC) change is another important integrating parameter for watershed prioritization under the GIS platform (Altaf et al., 2014; Malik & Bhat, 2014; Sujatha et al., 2014). Slope and drainage density give valuable information on the structural aspects of drainage basin, namely, linear, aerial,
and relief, which are important factors in prioritization as well as sustainable planning and management of watersheds. (Clarke, 1966; Javed et al., 2011; Malik et al., 2011). The drainage density maps provide an idea about the permeability of rocks and also indicate the yield of the basin. Remote sensing (RS) and Geographic Information System (GIS) play a significant role in the characterization and prioritization of watersheds of the past two decades.

In this research, the Kanakapura basin has been considered as a study area. Groundwater in the basin is mostly in the fractured aquifer as the weathered aquifer has been exploited over the years. The hydrology of the basin is rapidly changing due to urban agglomeration. This has also affected the quality of groundwater in the basin. Therefore, there is a need to protect the groundwater through proper land-use practices, prevent its pollution by establishing point sources, proper waste disposal, and large-scale rainwater harvesting.

The objective of this research is to utilize an integrated approach to prioritize the sub-watersheds for conservation and management of water resources based on the data on geological conditions, rainfall, morphometric parameters, hydrogeomorphic units, land-use, and land-cover mapping by applying weighted factor analysis.

This work aims to provide the sub-watershed wise status by integrating data sets to enhance the potentiality of the sub-watersheds.

So far, no research attempt has been made in this region to analyze and prioritize the parameters that influence the deterioration of watersheds based on various criteria. The current study will aid policymakers to plan maintenance interventions and resource allocation.

II. Study area

The Kanakapura watershed forms a part of the Arkavathi river basin which is one of the principal tributaries of the river Cauvery in Karnataka. The watershed is bounded between 12°16’N and 12°35’N latitudes, 77°15’E and 77°38’E longitudes, covering an area of about 81550 ha. (Figure 1). The entire watershed is divided into nine sub-watersheds, namely, Bannimukudlu, Bennagodu, DoddaAlahalli, Gadasahalli, Horalagallu, Kadihalli, Madarahalli, Maralebbekupe, and Mudagod, area of each ranges from 3000 to 25100 ha (NRSA, 1995). It has an average elevation of 638 m. The drainage pattern of the study area is dendritic to sub-dendritic in nature. The climatic characteristic is generally salubrious, temperature ranges from 28.4°C to 35.8°C, the lowest temperature being recorded during the month of January and the driest season is April–May. The average annual rainfall is 741 mm. Lithologic characteristics of this terrain are Granite and Peninsular Gneisses, and Charnockite is present in some places. In general, soil characteristics in this region are shallow to deep, drained to well-drained, yellowish to reddish-brown with moderate to high infiltration potential. Land-use patterns are predominantly agriculture and forest.

III. Data sources

The study area, Kanakapura watershed is delineated using Survey of India (SOI) topographic sheets bearing survey numbers 57 H/6, 57 H/7, 57 H/10, and 57 H/11 in a 1:50000 scale. Various thematic maps-rainfall, drainage, geology, slope, hydro-geomorphology, lineaments, land-use, and land-cover (LULC) characteristics were pre-

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**Figure 1.** Location map – Kanakapura watershed.
pared from topographic sheets, satellite images, and other reference maps, obtained from Karnataka State Remote-Sensing Center. Rainfall data from different rain gauge stations of the study area were collected from the statistical department, Government of Karnataka. Lithological information was extracted from the Geological Survey of India (GSI) map. Drainage density and hydro-geomorphic units were derived from LISS III + PAN (Figure 3) merged dataset and topographic sheet. The drainage map of the study area was generated from vectorization of the topographic sheet as well as satellite imagery, representing the network of streams and assigning stream orders (up to sixth order). LULC information was extracted from Landsat TM (Figure 4). The hydro-geomorphological map, generated for the Kanakapura watershed is based on a combination of visual interpretation of satellite image, topographic map, and on-site verification. LULC classification is based on the classification scheme developed by the National Remote-Sensing Agency (NRSA, 1995). The LULC maps were prepared and classified into built-up land, agricultural land, fallow land, plantation, forest, wasteland, and waterbodies, based on visual image interpretation from Landsat TM (https://earthexplorer.usgs.gov/), path 144, and row 51. This is done in combination with IRS-1D LISS III FCC of band 2,3,4 and SOI topographic sheets, Cartosat-1 digital platform. Slope and lineament density were derived from Digital Elevation Model (DEM).

It is evident from (Figure 9) that NE, NW, and SW parts of the area showed maximum relief (upto 1001 m above MSL), while the rest of the area is undulating and plain in the central part. Minimum relief is observed in the southern part, from 276 m above MSL.

**IV. Prioritization methodology**

It is essential to properly plan the developmental activities on a priority basis keeping in mind the huge investment involved, in order to achieve beneficial results. This resource-based, integrated approach is realistic and helps in addressing precarious areas to arrive at an appropriate solution. Each parameter was divided into different categories and weightage was assigned based on their relative importance. The weightage system followed in this research is completely based on local terrain and may vary from place to place. The weightage and ranks assigned for various categories of parameters is shown in Table 1 and the conceptual framework adopted for the identification of the priority zone is depicted in Figure 6.

**Rainfall**

Rainfall plays a significant role in the hydrologic process and is the primary source for groundwater infiltration. Average annual rainfall precipitation has been considered to recognize the possible capacity for infiltration. The annual rainfall map showed a declining pattern of rainfall across the study area’s south-east to south-west regions. Approximately 75% of the study region with an average annual rainfall of less than 700 mm, covering the sub-watersheds of Bennagodu, Bannimukudlu, Kodihalli, Maralebbeckupe, and Madarahalli was identified as very low or low infiltration potential zones, ranked 1 or 2.

**Lithology**

The present study area is a part of hard rock terrain consisting of four rock types, namely Charnokite, Closepet Granite, Peninsular gneisses, and Quartzite. These litho-units were considered for understanding groundwater distribution and occurrence. Charnokites are predominantly exposed in the study area’s southern region, showed high potential for infiltration, and it was verified with ground truth verification near the Sangam region (Figure 2). The study area’s litho-units were evaluated and correct weights were allocated based on their hydrogeological properties (Table 1). Figure 7 shows the distribution of Peninsular gneisses and Quartzites having a low capacity for penetration in the study area. The exposures of granite in the low-lying areas are weathered and decomposed, and in essence coarse-grained. Around 23% of the study area is having a low infiltration zone based on lithology. Due to lithological characteristics with very low penetration qualities, sub-watersheds Bennagodu, Bannimukudlu, and Madarahalli are under high priority range.

**Drainage network density**

The drainage pattern of the study area is dendritic to sub-dendritic in nature. Drainage density is defined as the ratio of the total length of the stream to the area of the drainage basin (Edet et al., 1998; Horton, 1932), as shown in Equation (1) below:

\[
D_d = \sum_{i=1}^{n} \frac{S_i}{A}
\]

where \(D_d\) is drainage density; \(S_i\) is the length of \(i^{th}\) stream in \(\text{km}\); \(A\) is the area under consideration in \(\text{sq. km}\).

A drainage density map provides an understanding of rock permeability and also indicates basin yield. High drainage density is counterproductive to the existence of groundwater, moderate drainage density has modest groundwater capacity and low/no drainage density is considered as a low groundwater potential zone (Todd & Mays, 2005). The drainage density map is classified into three categories, viz. low (<2 km/sq.km), medium (2 to 3 km/sq.km), and high (>3 km/sq. km), as shown in Figure 8. The drainage density in the study area varies between 1.71 and 3.04 km/sq.km indicating very coarse to coarse drainage texture. In the present study, it is understood that low drainage density indicates a region of highly permeable subsoil and dense vegetative cover.
Approximately 21% of the study area falls under the category of high drainage density. Bannimukudlu and Kodihalli sub-watershed having high drainage density implies a low groundwater potential zone.

**Slope**

The slope is one of the significant terrain parameters which determines infiltration and runoff in a region thereby acts as a controlling factor in the development and formation of landforms (Vittal et al., 2008). The entire study area is classified according to IMSD (1995) guidelines into seven groups based on the percentage of slope. In the present study, the slope area, considered for priority setting lies between gentle
slope (3%) to a very steep slope (greater than 35%). As the variation in slope is quite high, this parameter needs more focus. The result depicts sub-watersheds of Bannimukudlu and Kodihalli fall within the high priority category which has a low potential for infiltration. Around 37% of the region falls in the very steep slope category. A low slope (0–3%) indicates the existence of high potential groundwater zones, whereas a high slope indicates the presence of low potential groundwater zones as water flows off the surface rapidly. The slope is one of the prime factors for the positioning of the check dam. Lower the slope, the greater the chances of proper positioning of check dams. In the present study it is considered that due to more storage space and less runoff, nearly level and very gently slope locations are favorable for...
positioning of check dams. Figure 3 presents the slope map of the study area, showing an overall gentle slope toward the southeast region.

**Lineament density**

In hard rock terrain, lineaments exhibit faulting and fracturing zones resulting in higher secondary porosity and permeability and are strong groundwater indicators (Chowdhury et al., 2009; Dinesh Kumar et al., 2007). The capabilities of remote-sensing data in providing vital information about subsurface features that control the movement and storage of groundwater are of great importance in hydrogeological studies (Deepa et al., 2016; Rao et al., 2001; Sharma, 1979; Tolche, 2020). According to Greenbaum (1985) lineament density is defined as

![Figure 5. Cartosat1 DEM overlaid with sub-watershed boundary.](image)

![Figure 6. Conceptual framework adopted for identification of priority zone.](image)
the total length of all lineaments divided by the area under study (Equation (2))

\[ L_d = \frac{\sum_{i=1}^{n} L_i}{A} \]  \hspace{1cm} (2)

where \( L_d \) is lineament density; \( L_i \) is the length of \( i^{th} \) lineament in km; \( A \) is the area under consideration in sq. km.

The delineated lineaments from satellite data were transformed into different zones based on varying lineament densities, viz. low, medium, and high in the GIS platform. A region having high lineament density is appropriate for groundwater development (Sander, 2007). In the present study, lineaments are classified into three categories, namely, minor (length is less than or equal to 1.5 km), major (greater than 4 km), and intermediate (greater than 1.5 km and less than or equal to 4 km) lineaments. The Northeast and western parts of the study area witnessed high lineament density values, indicating good groundwater potential. The present study revealed that about 47% of the study area consists of low lineament density spreading over all sub-watersheds (Figure 10).

**Hydrogeomorphic units**

In prioritization of watersheds, geomorphology had the highest weightage due to its dominant role in the
movement and storage of groundwater (Thomas et al., 2009; Kumar et al., 2016). High infiltration zones have Channel Island, valley fill zones, and Inselberg. Medium infiltration potential zones have moderately weathered pediplains, shallow-weathered pediplains, pediment, pediment Inselberg complex has low infiltration potential. Very low infiltration potential zones are denudational hill, residual hill, and structural hill owing to their steep slopes and high runoff, unfavorable for groundwater prospecting. It is evident from Figure 11 that 47% of the study area is labeled as low to very low infiltration zones, especially the conditions of Bannimukudlu and Kodihalli sub-watersheds are not favorable for controlling the movement and storage of groundwater.

**Land use and Land Cover (LULC)**

The LULC maps of Kanakapura watershed were classified into six main classes, namely, built-up land (settlements), agricultural land (cropland, fallow, and agricultural plantations), forest (scrub degraded forest and forest plantation), wastelands (land with and without scrub, barren rock/stony waste, and industrial waste), and waterbodies (rivers, streams, tank) and others. They were delineated based on the image characteristics like tone, texture, shape, color, association, background, etc., using visual interpretation techniques. Field verification was performed if there is any doubt on feature identification. Higher and lower priorities were given to the sub-watersheds having a lower and higher
percentage of cultivated land, respectively. The built-up class was observed in almost all sub-watersheds, where Kodihalli sub-watershed occupied a large area of built-up land of about 56.42 sq. km. Sub-watersheds having a higher percentage of wasteland were given higher priority. The eastern side of Kanakapura watershed (Figure 12) – Bannimukudlu sub-watershed comprises of maximum wasteland area of 22.03 sq. km with a denudational geomorphic unit. About 45% of the study area falls under the low infiltration zone, is designated as a high priority area, characterized by built-up, forest, and wasteland which includes Bannimukudlu and Kodihalli sub-watersheds.

V. Weighted overlay analysis

The present study is an effort to prioritize sub-watersheds of the Kanakapura watershed. The Kanakapura watershed was delineated into nine sub-watersheds based on various morphometric parameters. The seven input layers considered for weighted overlay analysis are rainfall, lithology, drainage density, slope, hydrogeomorphic units, lineament density, and LULC. In order to bring all the thematic layers, having diverse, dissimilar inputs, into an integrated analysis, a common scale of value is applied to each layer. Hence, the sub-watersheds were categorized into four levels of ranking, ranging from 1 to 4, on the basis of their infiltration potential, namely: very low, low, medium, and high, respectively. Each layer is assigned a weightage based on its importance in contribution towards the groundwater recharge process. Lithology and hydrogeomorphic units were assigned the highest weightage, 20 each, drainage density, slope, and LULC were given 15 each, lineament density was assigned a weightage of 10, and rainfall was given the least.
VI. Results and discussion

Figure 13 represents the weighted overlay model of the study area. It is observed from Figure 13 that highly favorable groundwater potential zones are located along charnockite lithologic zones, sandy loamy soil zones, low drainage density areas, high lineament density locations, valley, inselberg zones, gentle to nearly level slope zones, high rainfall intensity zones, and waterbodies such as dam, streams, and tanks.

Moderately favorable zones for groundwater potential are located along with medium lineament areas, moderate drainage density zones, gneissic rock zones, sandy clay loamy, and clay zones, moderate, pediment zones, agricultural land, moderate to the gentle slope with medium rainfall intensity zones.

Finally, highly preferred and favorable zones for the groundwater resource conservation and management are identified in the southern and eastern parts of the study area, as shown in Figure 14.

The results from weighted overlay analysis reveal that Bannimukudu, Kodihalli, Dodda Alahalli, Gadasahalli sub-watersheds rank highest in weightage and considered as high priority zones. Out of the remaining five watersheds, Bennagodu, Horalagallu, Madarahalli, and Mudagod fall under the low and very low priority category, and Maralebbekupe falls under the medium category of prioritization.

The check dams are recommended to regulate the surface water, thereby increasing its influence over the command area and the groundwater levels. Percolation tanks are recommended across the streams to distribute the groundwater recharge over a large area and to have assured augmented water tables.

VII. Conclusion and recommendations

Prioritization of sub-watershed is the foremost task towards integrated and efficient watershed development and management, which will further aid decision-makers and planners achieve the appropriate allocation of resources. This paper summarizes the integrated approach for developing a multicriteria prioritization of sub-watersheds in the Kanakapura watershed area, Ramanagaram District, Karnataka. The entire area has been divided into nine sub-watersheds and prioritization has been carried out considering various parameters, including rainfall, drainage density, slope, drainage density, lineament density, hydrogeomorphic units, and LULC. On the basis of priority and cumulative weightage to each thematic map, the sub-watersheds are grouped into four classes: high, medium, low, and very low priorities.

The results of prioritization analyses reveal that Bannimukudu, Kodihalli, Dodda Alahalli, Gadasahalli sub-watersheds are under high priority. These sub-watersheds may be surveyed comprehensively for soil and water conservation initiatives, water resource development, and proper land-use planning. This will help in the creation of a detailed database under each natural resource theme, which is essential for effective and efficient conservation and management of deteriorating watersheds.

Based on the prioritization results, the following action plans are recommended.

(i) It is recommended to construct a major check dam near Dodda Halla stream (Figure 14) as well as two minor check dams in Bannimukudu sub-watershed, two check dams in Kodihalli sub-watershed, one check dam between Bennagodu and Madaralahalli sub-watershed and one percolation tank in Bannimukudu sub-watershed,
Doddala Ahalalli sub-watershed, two recharge wells in Horalagallu sub-watershed and one recharge well in Kodihalli and Doddala Ahalalli sub-watershed.

(ii) Implementation of water harvesting methods so as to avoid the wastage of rainwater from the watershed. This will also increase the groundwater recharge besides providing supplementary irrigation during Rabi or pre-monsoon season. Farmers should be encouraged to adopt soil conservation practices and construction of farm ponds.

(iii) Establishment of suitable soil and water conservation measures like contour bunding.

(iv) Lands with poor productivity and serious soil erosion can be brought under fodder, silvipasture, and social forestry development. These developmental activities help in reduced soil erosion, increased moisture conservation, and improved productivity of the soil.

(v) In general, the study area geologically belongs to hard rock terrain. Water harvesting and artificial recharge sites will improve water table level and meet water requirements during the summer season for irrigation of crops, and cater to both urban and rural area demands.

**Future scope of research**

Micro-level watershed analysis shall be conducted in the future to further explore the infiltration potential of the region in detail.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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