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Geospatial Technology Based Water Management Action Plan for South Forest Division of Nilgiris, Tamil Nadu

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Recent climate change impacts rainfall patterns, increasing wildlife and livestock populations in higher densities, which are likely to aggravate water scarcity in forest areas. A sustainable water management strategy and action plan based on scientific inputs are crucial and need of the hour to resolve the water scarcity problem. Hence, the study aims to prepare an action plan and water management strategy for rangelands of Nilgiris using geospatial tools.
Study Design: Field survey was conducted to identify the existing water storage structures and water requirement and ASTER GDEM and GIS were used to prepare the water management strategies for Nilgiris south forest division.
Place and Duration of the Study: The study was carried out in Nilgiris south division located in between 76^0 28' 08''and 76^0 44' 08" East longitude and 11^0 10' 81''and 11^0 31' 80" North latitude during 2014-2016.
Methodology: The study area has been delineated as macro watersheds, and the altitude, slope, forest cover and drainage lines were extracted from ASTER GDEM for generation thematic maps. Rainfall data for twenty years (1995-2014) was collected and runoff was worked out using runoff

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coefficient of a different land. A field survey was conducted for identifying the existing water storage structures, spatial occupancy of herbivores, spread and water requirement of invasive species in the Nilgiris south forest division.
Results: GIS based thematic maps for slope, contour, area coverage under forest range and macro watershed have been prepared, and water availability and water balance components like runoff and evapotranspiration have been determined. After identifying water availability and water balance according to the site conditions and strategies one Earthen cum masonry embankment, 2 Earthen pond with Major check dam, 2 Masonry embankments, 2 Major check dam 7 Medium check dam 100 Minor check dam, 1 RCC Embankment and 99 gabion check dams in South forest division of Nilgiris.
Conclusion: Suitable locations were identified and location specific water harvesting structures have been suggested to store 68844 cum of water.

Keywords: Geospatial technology; water management; water availability; Nilgiris.

1. INTRODUCTION

Water serves as a critical habitat factor that determines the type of vegetation and its distribution and hence the associated animals of the region. The availability of clean water, especially during summer and drought is vital for supporting and maintaining the wildlife communities in the forest ecosystem [1]. Landscape transformations due to increasing populations, urbanization, encroachments, deforestation, and overexploitation of water in catchments, degradation and fragmentation of watersheds ultimately affect the forest hydrology and reduce the availability of quality water. Climate change and increasing wildlife and livestock populations in higher densities will aggravate water scarcity in forest areas. A sustainable water management strategy based on wildlife densities, rainfall, and vegetation is crucial to resolve the water scarcity problem. Water management strategy is a plan or a specific project to meet a need for additional water by a discrete user group, which can increase the total water supply or maximizing an existing supply [2]. Population growth and potential climate change are increasing pressure on water management [3], hence water management plays a significant role in protecting the environment [4]. Site-specific water management could be a solution to conserve water and improve water use efficiency (WUE), which is the ratio between effective water use and actual water withdrawal in the field [5]. Water management is crucial because of its intrinsic imbalance across various organisms, and proper water management implies long-term and stable performance [6]. The quantity and quality of water have been widely affected by native forest buffers in forested and agricultural watersheds [7] and the forest cover affects the nutrient and sediments in a small watershed [8]. The total annual precipitation may vary from place to place therefore location specific water management strategies should be derived [5] for the sustainability of forest ecosystem [6].

Preparing a water management plan becomes easier with precision agriculture tools, such as GNSS, GIS, yield mapping and remote sensing [9,10,11,12]. Bluewater is mostly focused for agricultural water policy and management, but additional gains in the water productivity of the global food systems during the 21st century are likely to arise from improvements in greenwater management [13]. Many models have shown the potential of green water management to significantly improve green water use at global and watershed [14,15,16]. It is also essential to improve the productivity of green water usage in agriculture, particularly in rain-fed agricultural systems in semi-arid regions, where water productivity is very low [17].

Forests and trees are an integral part of the Nilgiris mountainous ecosystem and are important water sources for the surrounding regions. Though Nilgiris receive higher rainfall with high intensity, the wildlife and vegetation in forest areas face acute water shortages during the summer season. Lack of location specific water harvesting and recharge structures, frequent dry spells and bi-model rainfall distribution due to climate change and over exploitation of groundwater for agriculture and domestic use in upper and adjacent areas of forest reserves are the major cause of water scarcity in the Nilgiris forest division. Construction of water harvesting structures at appropriate sites will increase the water availability, groundwater recharge and water table [18]. These structures can also check soil erosion and runoff from the forest [19]. Major benefits of water harvesting include efficient use of available natural resources, augmentation of existing supply capacity, reduced contaminant loads into water bodies, reduced soil erosion and environmental protection [20,21,22]. Hence, creating appropriate soil and water management structures in the forest reserve is the possible solution for mitigating water shortage. Geospatial tools, such as Remote sensing, GPS, and GIS, can be successfully used to derive effective location-specific water management strategies [9]. Water management strategies in forests require applying modern tools through a lens that considers ecosystems the wildlife, vegetation and other natural resources holistically. An attempt has been made to prepare an action plan and water management strategy for rangelands of Nilgiris using geospatial tools.

2. STUDY AREA

Nilgiris south division is situated in the North West part of Tamil Nadu state surrounded by Nilgiris north forest division on East and North, Gudalur and Mukurthi national park on West and Coimbatore division and Kerala on South with a total area of 54,286 ha including 30,249 ha protected forest areas (Fig. 1). It is geographically located between 760 28' 08''and 760 44' 08" East longitude and 110 10' 81''and 110 31' 80" North latitude and comprises seven ranges, namely Kundah Korakundha, Udhagai south, Governorshola, Parson's valley, Pykara and Naduvattam.

Although the South forest division is situated in the tropical zone, this region enjoys a sub-tropical to temperate climate by virtue of its varying altitudes. This region's average maximum and minimum temperature is 23.1ºC and 5.1ºC, respectively with the coldest December and the hottest April month. Frosty nights are common during January and February. The south forest range receives an average annual rainfall from 1200 to 2000 mm that spread over monsoon, post monsoon, winter and summer with most of the rainfall concerted during June to November. The region receives bimodal rainfall from South- west monsoon (June to August) and North east monsoon (September to December). Storm rainfall more than 12.5 mm occurs during July, October and November months that can cause runoff and soil erosion. The lithology of the study area the charnockite group of bedrocks, covered by the ubiquitous red laterite or lateritic soil. There are five major types of soil viz., lateritic soil, red sandy soil, red loam, black soil, alluvial and colluvial soil found in the Nilgiris south division.

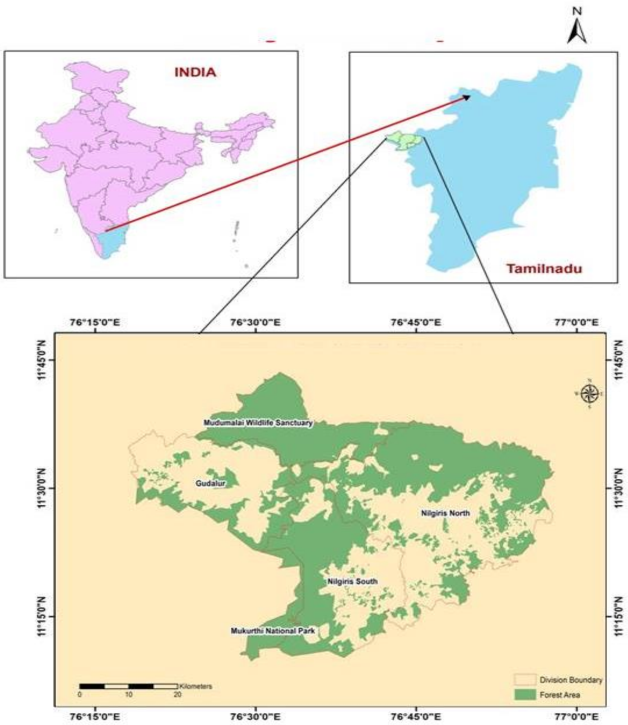

Fig.1 Study area map

3. METHODOLOGY

The study area has been delineated as macro watersheds with freely available global ASTER GDEM for preparing the water management strategies on a watershed basis. The altitude, slope, forest cover and drainage lines were also extracted from ASTER GDEM for thematic maps preparation. The ASTER GDEM data for this study is downloaded from http://asterweb.jpl.nasa.gov/gdem.asp website and imported in ArcGIS.

Followed by delineation of macro watersheds, the forest range (subdivisions of forest districts) have been delineated within the watershed. Rainfall data for twenty years (1995-2014) was collected and runoff was worked out using runoff coefficients of a different land. A field survey was conducted for identifying the existing water storage structures, spatial occupancy of herbivores, spread and water requirement of invasive species in the Nilgiris south forest division. Water availability and water balance served as important criteria for determining the number of location-specific water harvesting structures and their storage capacity. Water availability was calculated by water balance method as described below:

$$\sum Wa = \sum (1/3*Ro) - \sum Rs - \sum Ms - \sum ETo$$

Whereas
Wa – Water availability for harvesting
Ro - Runoff
Rs – Storage capacity of existing reservoirs
Ms – Storage capacity of minor structures
ETo – Evapotranspiration

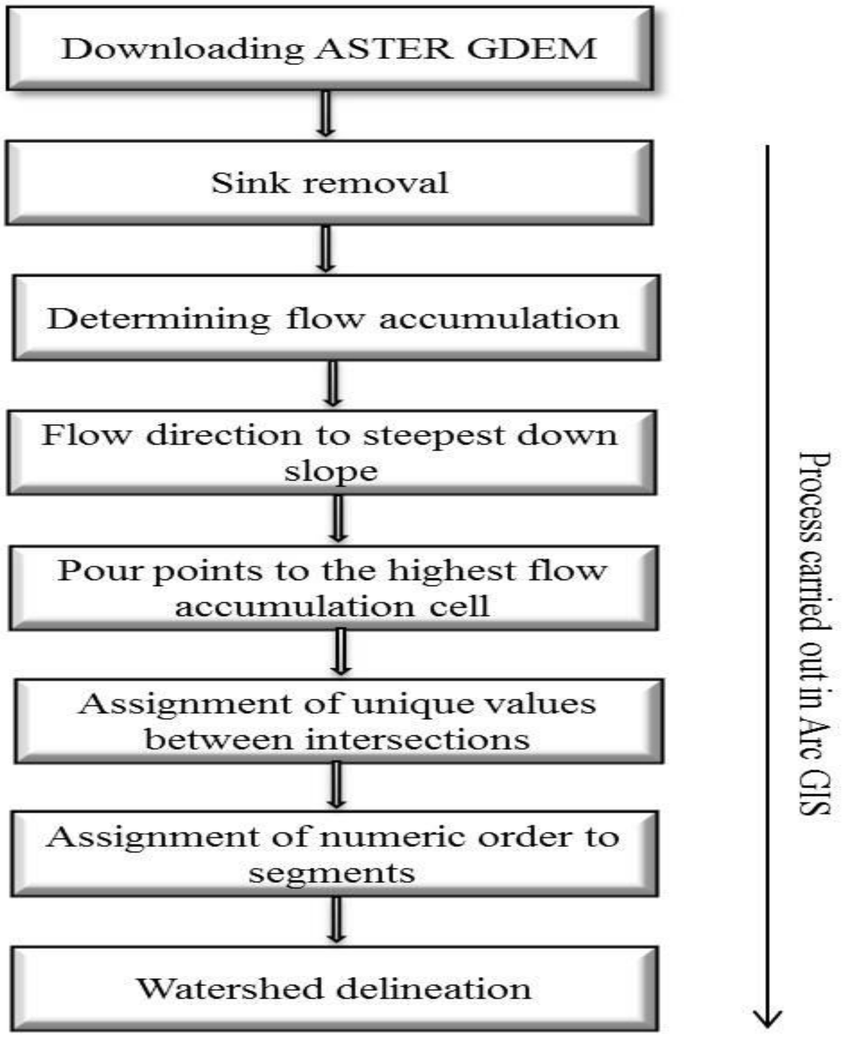

Fig. 2. Methodology adopted for delineating watershed and stream feature from ASTER global DEM data

4. RESULTS AND DISCUSSION

4.1 Watershed Delineation

The Nilgiris South forest division is one of the forest administrative divisions of five forest divisions of Nilgiris district namely, Nilgiris South, Nilgiris North, Gudalur, Mudumalai wildlife sanctuary and Mukurthi national park. Freely downloaded ASTER GDEM with a spatial resolution of 30 m is used for watershed delineation in Arc GIS. ASTER GDEM is a highly accurate DEM covering all the land on earth regardless of size or location of target areas and easy-to-use. Totally 34 macro watersheds have been delineated in the South Forest Division. Delineated macro watersheds and drainage lines are depicted in Fig. 3.

4.2 Slope, Elevation and Contour

The region's slope plays a crucial role in selecting the best site for water harvesting to store maximum water as it influences the runoff, sedimentation ratio, recharge, surface water velocity, and other essential parameters to design the structure [23]. Slope map is generated from the ASTER GDEM and five slope classes were classified. South forest division has wide slopes ranging from level surface on tabletop hills in Udhagai south range to deep slope in Kundah range hills. Very deep slope of 33 % and above is seen in Kundah and Naduvattam ranges. The maximum forest reserve in the South division is under slope ranges of 16 % and above.

The elevation and contour maps were prepared from the ASTER GDEM (Fig.5). The elevation of the entire South forest division is ranged from 600 m to 2600 m above mean sea level. Korakundha, Parsons Valley, Governorshola, Pykara and Naduvattam ranges are in high altitude hill ranges. A geographically referenced contour map at 30 m interval for South forest division was prepared.

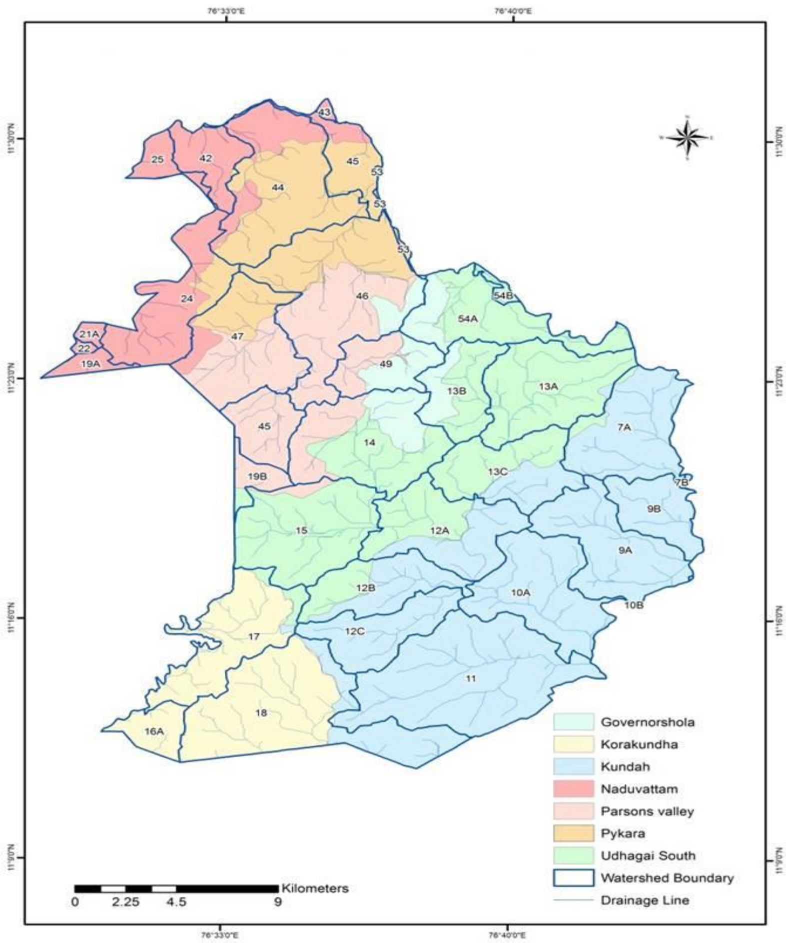

Fig. 3. Drainage map of macro watersheds in Nilgiris south forest division

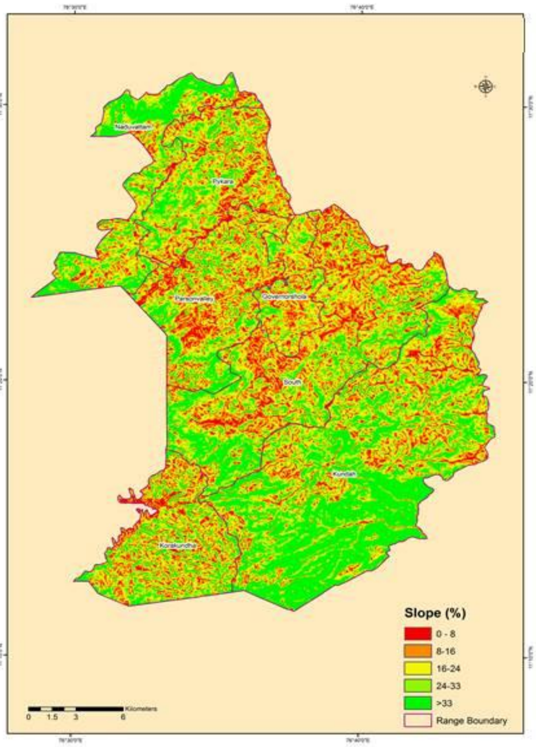

Fig. 4. Slope map of Nilgiris south forest division

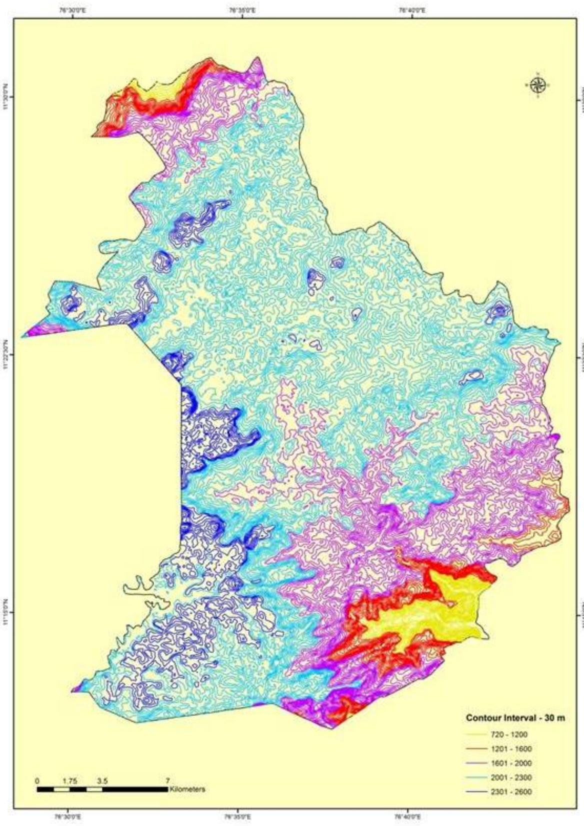

Fig. 5. Contour map of Nilgiris south forest division

4.3 Forest Land Use Pattern

Land use pattern is fundamental to found the runoff potential of any site. South forest division is dominated by Native forest with 15,184 ha followed by exotic forest species (13073 ha). The grasslands and swamps contributed for 7 % of the total area (Fig 6). Vegetation cover promotes infiltration, reduces runoff, and increases water harvesting potential [24]. According to a broad scale study, invasive alien plants are consumptive water-users and may have reduced river flows. The major exatic species found in the region are: *Michelia Nilgirica, Michelia Champaca, Gordonia Obtusa, Xantolis tomentosum, Sideroxylon tomeutosum, Meliosma wightii, Elaeocarpus oblongus, Elaeocarpus munroii, Cinnamomum wightii, Litsea wigutianan, Neolitsea zeylanica, Evodia luna ankenda, Nothapodytes foetida, Ilex wightiana, Ilex epiculata, Glochidion neilgherrense, Daphniphyllum glaucescens, Machilus macarantha, Syzygium arnottianum,* and *Syzygium montanum*.

4.4 Water Availability

Water availability at Korakundha, Kundah, Parson's valley and Naduvattam ranges are higher and have vast scope for harvesting rainwater through additional structures. Governorshola and Pykara ranges have sufficient water availability and limited scope for additional structures as water has already been harvested in existing reservoirs. South forest division has 21 numbers of reservoirs for power generation as well as domestic use. All the 21 reservoirs are receiving water from 187.2 Sq. MLS of the surrounding catchment area. 18284.2 MCFT water is stored in these reservoirs. The water available in these reservoirs is being utilized by wild animals also. Department of forest has constructed large numbers of water harvesting structures like check dams in gullies, larger and smaller percolation ponds, earthen ponds. Surface and subsurface water harvested and stored in these structures water is being directly used by wild animals and elephants.

Existing structures could create a storage capacity of 517.6 Mcum and there is the scope to harvest 0.068 Mcum water through minor structures. Water available for harvesting in different forest ranges has been given in Table 1.

4.5 Identification of Man Animal Conflict Regions

Man animal conflict is seen across the Nilgiris, including monkey menace in the urban areas, crop raiding by ungulates and wild pigs, depredation by elephants, cattle and human killing by tigers and leopards. Damage to agricultural crops and property, killing of livestock and human beings are some of the worst forms of man-animal conflict. In south forest division elephants are found in Geddai, Mulligoor and Naduvattam (27th mile) areas and damage crops, killing human beings and livestock in nearby villages. Indian guar, wild monkeys (Macaque's), sambar deer also becoming a menace to agricultural production. All these areas are identified and mapped for selecting the site for structures.

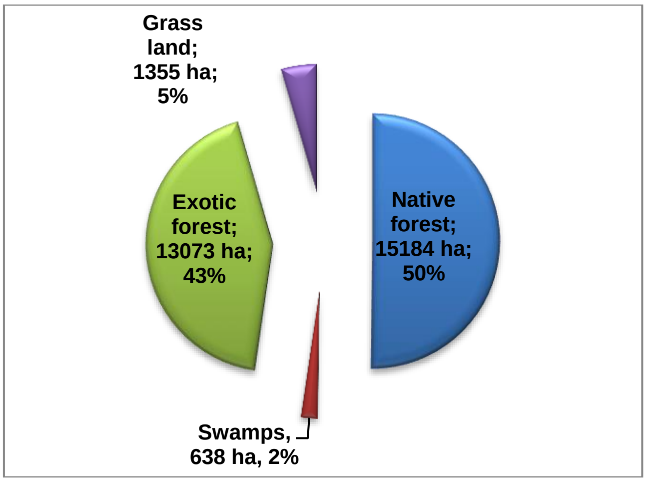

Fig 6. Forest Land Use Pattern in South Forest Division of Nilgiris

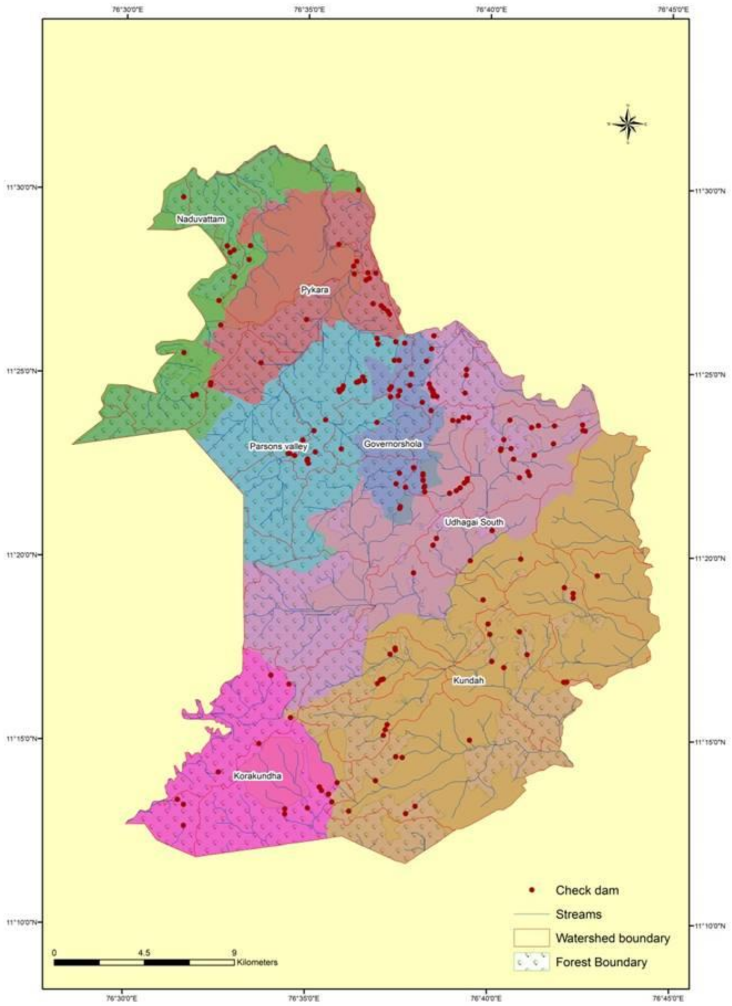

Fig. 7. Location of existing water management structures in Nilgiris south forest division

4.6 Site Selection Criteria

The Site selection criteria for new structures have been derived based on the following aspects.

1. Water availability and perennial streamflow during summer or dry season
2. Spatial occupancy of large mammals like elephants/guars in a particular location and their movements to the outside forest reserve
3. Distance between existing water harvesting structures
4. Distance from the agricultural fields or tea estates
5. Distance from the human habitats
6. Less man animal conflict areas
7. The structures should be eco-friendly so that they will not hurt any wildlife in the forest reserve.
8. The structures increase the forest vegetation cover and supply food to the wildlife
9. Structures requiring limited construction materials and most can be done by earthwork is recommended

4.7 Water Management Strategies

The following strategies were adopted for developing a water management action plan in the South forest division of Nilgiris.

1. Improving water retention capacity in reserve forests and within water bodies
2. Increase the water availability period in the streams by adopting suitable recharge structures in upstream catchments
3. Creation of permanent water harvesting structures for drinking purpose of wild animals

4. Improve the water spread area and capacity of existing water harvesting structures
5. Enhancing groundwater recharge and improving groundwater availability
6. Extending period of water availability in the water harvesting ponds, streams by adopting suitable engineering structures and increasing capacity
7. To reduce the man – animal conflict on water sharing
8. Managing runoff water efficiently for improving greenery of the forest project through adopting in situ moisture conservation measures
9. Increasing water availability in the existing structures by repairing and de-silting and modification of structures

4.8 Water Management Action Plan

In many parts of the world, the collected rainwater from natural precipitation is the only source of water supply and it is considered an economical and useful method. Proper water harvesting techniques will mitigate the problems of soil erosion and flood to a large extent [25]. It will also improve the wildlife habitats and provide sufficient water to wild animals. After identifying water availability and water balance specific water management plan for Nilgiris south forest division is recommended. According to the site conditions and strategies the following structures have been proposed for South forest region (Table 2).

Earthen cum Masonry Embankments are suitable for harvesting and collecting water across wide nallah / depressed portions in the forest areas with huge catchment. Two earthen cum masonry embankments at Governor shola and Pykara ranges with 25 to 40 m length followed by earthen bund with 8 to 10 m bottom width and 2.5 to 4.0 m top width. These structures can create 5525 cum storage capacity. Earthen ponds are the most common and simplest type of water harvesting ponds for locations having relatively larger water spread area. These are usually constructed by deepening existing depression / natural drainage and forming a check dam with weir draining excess water. The excavated soil has to be placed in the sides to support the check dam and to be stabilized with grass planting. One earthen pond with 4896 cum storage capacity is recommended. Two masonry embankments with stone or brick masonry across a watercourse for each having 1925 cum storage capacity are proposed for harvesting and collecting water across in deep gully having 2 m depth and having heavy flow.

Two major check dams with 6300 cum storage capacity have been proposed in the upstream side across the gullies having wide width and more water spread area. The check dams with 25 to 40 m length and 1.5 to 2 m top width can be constructed by either by rubble stone masonry or any other suitable masonry. Whereas medium check dam is to be constructed across the gullies having smaller width with 11 to 24 m length and 1.0 to 1.5 m top width. To create 8820 cum water storage in totally seven medium check dams were proposed. A minor check dam is to be constructed across the gullies having smaller width with or without water spread area in the upstream side with 2 to 10 m length and 0.75 to 1.5 m top width. One hundred minor check dams are proposed in South forest divisions to create 28130 cum water storage capacity. These check dam structures are multifunctional used for groundwater recharge and water storage. RCC embankment is constructed by reinforced cement concrete across a watercourse for storage. The RCC wall will have the length of 25 to 30 m length. These are suitable for harvesting and collecting water across the watercourse where masonry structure is not possible due to the swampy nature of the soil. One structure with 5798 cum capacity is proposed in Parson's valley range. These proposed structures can create about 68844 cum water storage in the Nilgiris south forest division [26].

Gully control or gully plugging measures ie Gabion check dams in the middle and lower reaches is necessary for gully erosion control. Simple grade stabilization structures called check dams may consist of a wall built of gabion boxes across the stream. The spillway is formed by placing 1 m x 1 m gabion box on either ends of the wall. The check dams with more than one meter drop should have a gabion apron to prevent scouring. Ninety nine gabion check dams are proposed as gully plugging/gully control structures in South forest division of Nilgiris.

Table 1. Water balance status of forest ranges in south forest division of Nilgiris

S.No	Forest Range	Rainfall (mm)	Runoff (mm)	Water availability (Mcum)	Harvestable water (Mcum) (1/3)	Reservoir (Mcum)	Minor structures (Mcum)	Balance to be harvested (Mcum)
1	Kundah	1416.0	609.2	354.40	118.13	62.13	0.008797	0.005063
2	Korakundha	3261.6	2454.8	698.20	232.73	145.63	0.004907	0.007583
3	Udhagai	1232.1	496.7	302.10	100.70	54.26	0.006969	0.015067
4	Governorshola	1787.8	1052.4	188.30	62.77	40.15	0.008329	0.005806
5	Parson's Valley	1632.3	896.9	488.80	162.93	105.63	0.005495	0.015204
6	Pykara	1021.8	233.7	151.80	50.60	28.56	0.004101	0.015101
7	Naduvattam	2871.1	2003	483.70	161.23	81.26	0.002783	0.004738
	Total			2667.30	889.10	517.62	0.041380	0.068563

Table 2. Proposed water management structures with storage capacity in different range limits of south forest division of nilgiris

Name of the Structure	Governorshola	Kora kundha	Kundah	Naduvattam	Parson's valley	Pykara	Udhagai South	Grand Total	Capacity of one structure (cum)	Total Capacity (cum)
Earthen cum masonry embankment	1	-	-	-	-	1	-	2	5525.0	11050.0
Earthen pond with Major check dam	-	-	-	-	-	-	1	1	4896.0	4896.0
Masonry embankment	-	-	-	1	-	1	-	2	1925.0	3850.0
Major check dam	-	-	-	-	-	1	1	2	3150.0	6300.0
Medium check dam	-	2	-	-	3	-	2	7	1260.0	8820.0
Minor check dam	1	18	18	10	20	16	17	100	281.3	28130.0
RCC Embankment	-	-	-	-	1	-	-	1	5798.0	5798.0
Gabion check dam	7	12	12	8	31	13	16	99	Gully control structures	
Total	**9**	**32**	**30**	**19**	**55**	**32**	**37**	**214**	-	**68844.0**

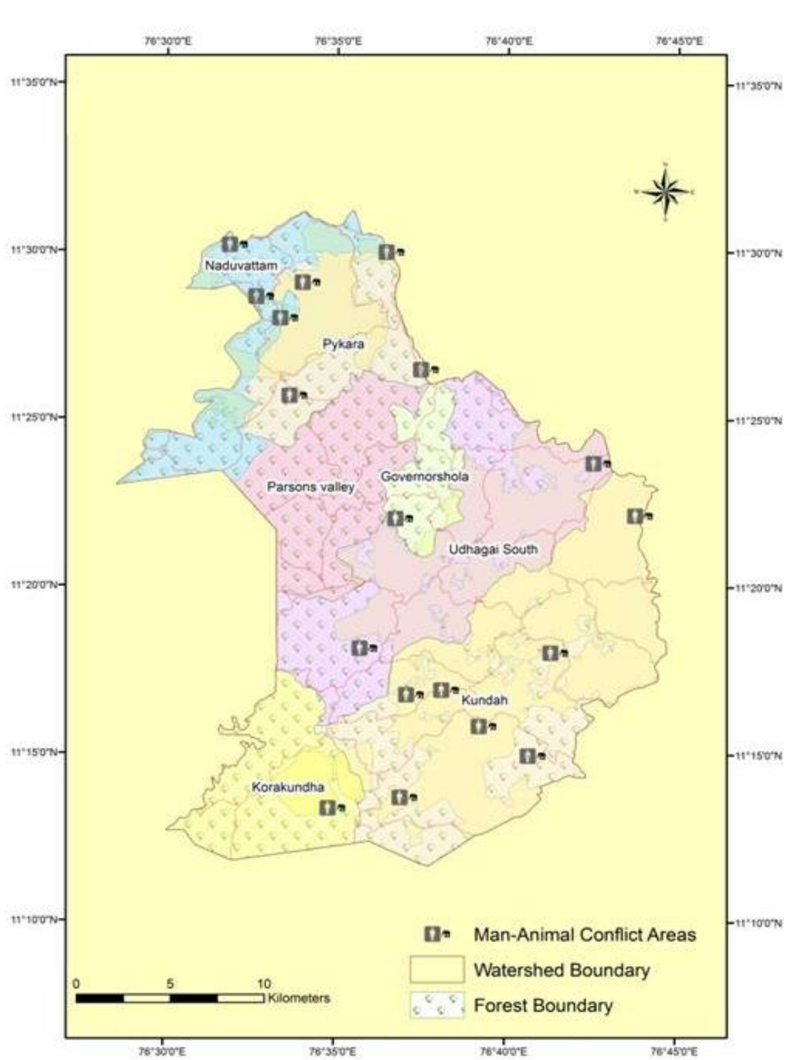

Fig. 8. Man animal conflict areas in south forest division of Nilgiris

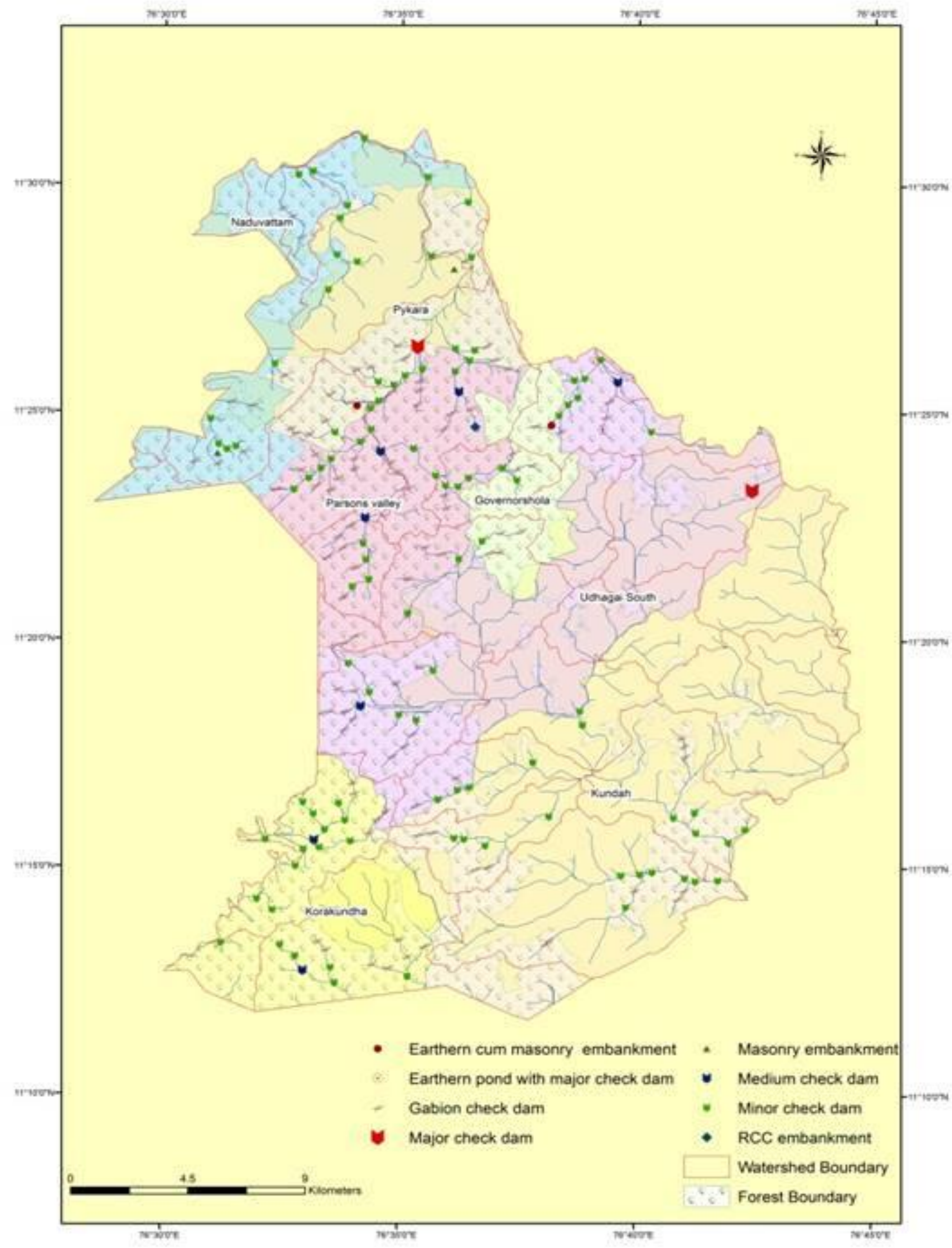

Fig. 9. Location of proposed water management structures in Nilgiris south forest division

5. CONCLUSION

Water scarcity is a global challenge, however it can be managed with modern geospatial tools. GIS based thematic maps for slope, contour, area coverage under forest range and macro watershed have been prepared for the study area. Water availability and water balance components like runoff and evapotranspiration have been determined. Suitable locations were identified and location specific water harvesting structures have suggested creating about 68844 cum water storage in Nilgiris south forest division.

6. RECOMMENDATIONS

The water availability in Nilgiris south forest division can be enhanced immediately by repairing and desilting existing water harvesting/gully control structures. The proposed new structures may be undertaken based on priority rather than taking up a large number of smaller structures. Field level functionaries like range forest officers and foresters have to be trained for the maintenance of water harvesting structures in reputed organizations. Water harvesting structures in protected areas may be used for fish culture. To protect the structures and wild animals Eco-tourism may be discouraged in the protected areas. The climatic data and inventory of existing water harvesting structures at reserve forests should be digitized for future water management studies.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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