Hydrological regime in Sacred Groves and Non-Sacred Groves of Central Western Ghats

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***Abstract*– Sacred Grove (Relic forests /Devara Kadu) refers to the forests that are protected and preserved through generations by the village communities by understanding the importance of biological and hydrological services provided. Anthropogenic alterations in these forests are comparatively less due to the socio-cultural beliefs, at the same time many groves are either lost or shrunk endangering biodiversity and effecting the hydrological regime. Several studies show that, relic forests and water resources are associated to each other implying the presence of perennial streams, swamps, springs, lakes, ponds, wetlands surrounding the groves that aids in sustaining the hydrological regime (environmental flows) across seasons. Water being perennial in the groves has led to i) favorable microclimates and habitats supporting numerous fauna and flora, ii) catering societal demands in the vicinity. There is a very little knowledge on hydrological regime and water yield in these watersheds comprising sacred groves compared to other landscapes. This communication attempts to understand the hydrological behavior of selected ecologically sensitive watershed in Uttara Kannada and Shimoga districts of Karnataka. Monthly field measurements were carried out between July 2014 to April 2016 to account the variability of water yield using i) area velocity method for discharge measurements across streams, ii) measuring ground water depth in open wells. Remote sensing and GIS were used to understand the land use, topography in these catchments. Comparative assessment of catchments with sacred groves and non-sacred groves showed that, water bodies associated with the sacred grove were perennial with 5 folds' higher water yield during pre-monsoons (summer) than the non-sacred groves. Water yield in the non-sacred groves were relatively high during the monsoons indicating lower infiltration. The hydrological study also revealed that, presence of natural forests in the catchments such as Kodkani (Kathlekan non sacred grove), Nanalli (Yaana non sacred grove) even though excluded from sacred grove are also equally competent as sacred groves in maintaining the hydrological regime. Cluster analysis of catchments (streams) reveled that SG's and NSG's form separate clusters indicating that the SG and NSG behave differently. The outcome of the field investigations emphasises the critical role of natural/relic forests in sustaining the hydrological regime.**

***Keywords*– *Sacred groves, Land use, Hydrological regime, Watersheds, Remote Sensing*.**

INTRODUCTION

Western Ghats is one among the 35 rich biodiversity hotspots [1] across the world harboring numerous diverse flora and fauna species [2] including endemic, endangered species. The hill ranges of Western Ghats in India range extend from Gujrat to Tamil Nadu for a length of 1600 km [3] giving birth to numerous stream and rivers flowing in Southern India. The pristine environment of Western Ghats is under severe treat due to anthropogenic activities such as large scale land use changes for agriculture, monoculture, *etc.* [4, 5, 6], construction of small and large hydro projects [7, 8], altering catchment characteristics there by affecting hydrological regime, depriving fresh water resource to the users (environmental and societal) across the catchment [9, 10, 11]. The flow regimes determine the quality as well as health of the river and flow regime is the primary driving force that influences riverine and aquatic ecosystems, habitats, spices richness and diversity, river morphology, biotic life, river connectivity [12]. Numerous studies across the globe indicate increasing fresh water demands and large scale withdrawal from the fresh water for meeting various societal needs (human centric planning) such as domestic, irrigation, industrial, power, etc., have led to large scale compromise and degradation in the natural flows affecting aquatic, terrestrial and riverine ecosystems that support native species and sustained ecosystem that provided important goods and services [13 - 22]. A very few studies in Western Ghats have been carried out in understanding the landscape dynamics and hydrological regime [8, 12, 23, 24]. In the current communication objective is to understand the role of relic forests on surface and subsurface hydrological regimes by continuous monitoring of selected wells, rivers and streams of select catchments consisting sacred groves in Uttara Kannada and Shimoga District, Karnataka. There by helping the decision makers to understand role of undisturbed forest in maintain hydrological regime and catering to the societal water needs.

STUDY AREA

In order to understand flow dynamics (variations in hydrological regime, water yield) from protected forests, based on rigorous field visits and continuous discussion carried out by the team, pairs of catchments consisting i) sacred groves (SG) and ii) non-sacred groves (NSG). About 7 pairs catchment were considered for the analysis namely

1) Vibuthi as SG and Mabgi as NSG.
2) Yaana as SG and Nanalli as NSG.
3) Kathalekan as SG (measured at 5 locations) and Kodkani as NSG.
4) Torme as SG and Kanalli as NSG.
5) Rameshwara kan SG and Pandavarakodllu as NSG.

Figure 1 depicts the spatial distribution of selected catchments and Table 1 gives the details of each catchment. The pairs of catchments selected for analysis having similar characteristics.

Table 1: Description of catchments considered for comparative assessment

Sl. no	Catchment / Stream	SG / NSG	Location	Taluk	District	Area (ha)	Annual Rainfall (mm)	River	Stream Order*	Measurement
1	Vibuthi	SG	Achave	Ankola	Uttara Kannada	736.1	4614	Gangavali	3	Stream
	Mabgi	NSG	Manigadde	Ankola	Uttara Kannada	176.4	4493	Gangavali	3	Stream
2	Yaana	SG	Yaana	Kumta	Uttara Kannada	122.3	4631	Aghanashini	3	Stream
	Nanalli	NSG	Yaana	Kumta	Uttara Kannada	84.3	4689	Aghanashini	2	Stream
3	Kathalekan	SG	Malemane	Siddapura	Uttara Kannada	120.2, 16.9	5025	Sharavathi	2	Stream
	Kodkani	NSG	Kodkani	Siddapura	Uttara Kannada	115.2	4713	Sharavathi	2	Stream
4	Torme	SG	Kudagunda	Siddapura	Uttara Kannada	55.2	4758	Aghanashini	2	Stream
	Kanalli	NSG	Avalalli	Siddapura	Uttara Kannada	7.7	4703	Aghanashini	1	Pond
5	Pandavarakodlu	SG	Aaneguli/ Maradavalli	Sagara	Shimoga	11 (65.1)	3517	Sharavathi	1	Pond, Well
	Rameshwara kan	NSG	Hulkodu	Sagara	Shimoga	8.99 (79.4)	3292	Sharavathi	1	Stream

*Order as per 1:50000 Survey of India Topographic sheets

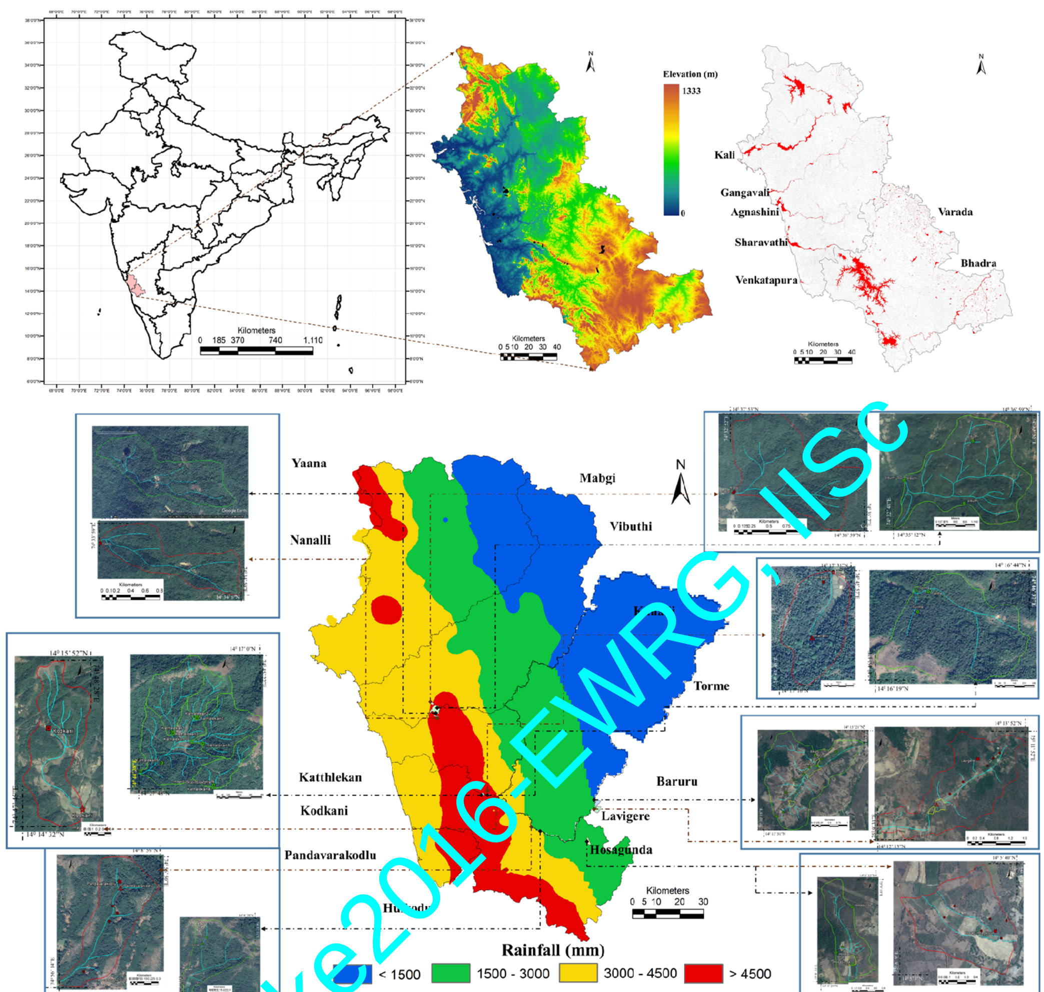


Figure 1: Study Area

METHOD AND DATA

Figure 2 describes the method involved in understanding the hydrological regime of catchments under carried landscape conditions. The method can be divided into three groups (i) Data acquisition, (ii) Land use assessment, and (iii) Hydrological assessment.

(i) **Data acquisition**: Data acquisition involves collection of (a) Remote Sensing Satellite data [25] such as RADAR data – SRTM 30m for Topography assessment, Optical Data – Landsat 8 for land use analysis, aided with online virtual globe data such as Google earth/Bhuvan [26, 27]; (b) Collection of Ancillary data such as Survey of India 1:50000 Topographic sheets [28] that aids in understanding the landscape, extraction of drainage network, identification of administrative division, French institute maps [29] for forest type identification; (c) Field data acquisition with aid of GPS for (i) Creating training data sites, (ii) Collection of control points for optical satellite data preprocessing, (iii) Surface and subsurface quantification of water resources.

(ii) **Land use assessment:** Optical satellite data collected from United States Geological Survey were preprocessed for geometric rectification [30] using control points obtained from field survey, ancillary data and virtual globe datasets. Radiometric corrections were applied for each bands using image enhancement techniques [31, 32]. False colour composite was formed by stacking various spectral bands of the obtained satellite data to identify heterogeneous features. Training sites were digitized based on Field data, Ancillary data, Topographic sheets, French Institute maps on FCC to develop signatures for Land use classification. 60% of the training sites were used to classify and 40% for accuracy assessment. Gaussian Maximum likelihood classifier algorithm was used to classify the Satellite data [33, 34]. Catchment boundaries were delineated based on the 1: 50000 Topographic sheets and radar data (SRTM 30m), which were further used to extract land use for select streams, lake catchments.

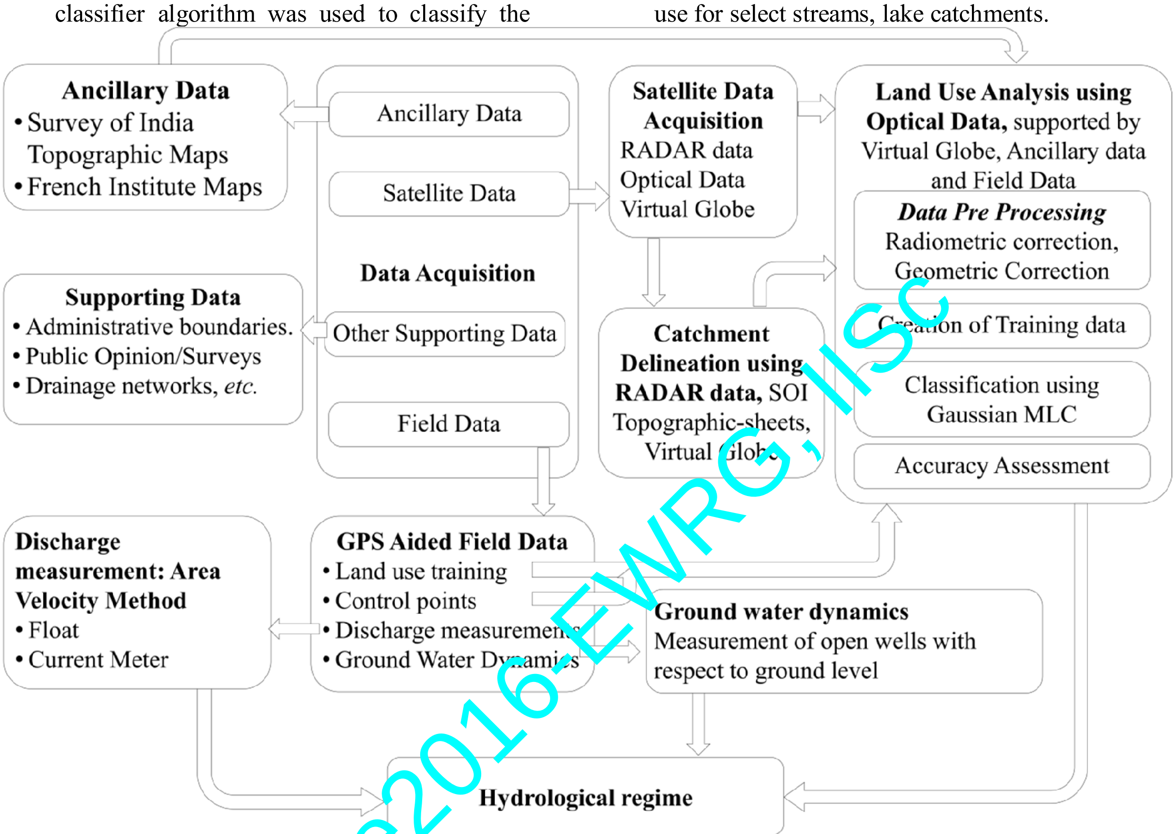


Figure 2: Method involved

(iii) **Hydrological assessment:** Continuous (monthly) field observations were carried out at selected lakes, ponds, river/streams and wells. Flow measurements were carried out using area velocity method [35, 36] (Figure 3), where in discharge was calculated at every grid (eq.1). Where Q is the discharge measured as cumec (m^3/s), A_i is the cross sectional area of section in terms of square metre (m^2), V_i is the velocity of section i measured as metres per second (m/s), i represents number of sections measured Velocities were measured using, (i) Current meter, (ii) Floats depending on the quantity of water flow. A pre calibrated current meter is used to measure the velocity of flow, where in the velocity if the function of number of revolutions and time taken to make the same. Floats are used when the velocities and depth of water are too high when the current meter cannot with stand the force or too low than the height of current meter (< 10 cm depth). Floats are allowed to flow for a certain distance and the time taken to travel the distance is measured to compute velocity. Due to the variations in the catchment area, the discharges were normalized (discharge to area ratio) as mm/day (or liters per hectare per day) is used as the measure of comparison between the SG's and NSG's. Open wells were monitored to understand variation of ground water across seasons by measuring the depth of water below the earth surface using Open wells (Figure 4).

Comparative assessment of the catchment land use characteristics and flow (surface and ground water) dynamics was made to understand the role of land use on the hydrological regime. Statistical clustering analysis was carried out to understand the similarity between study sites.

$$Q = \sum_{i=1}^{n} A_i . V_i \quad \text{------- eq.1}$$

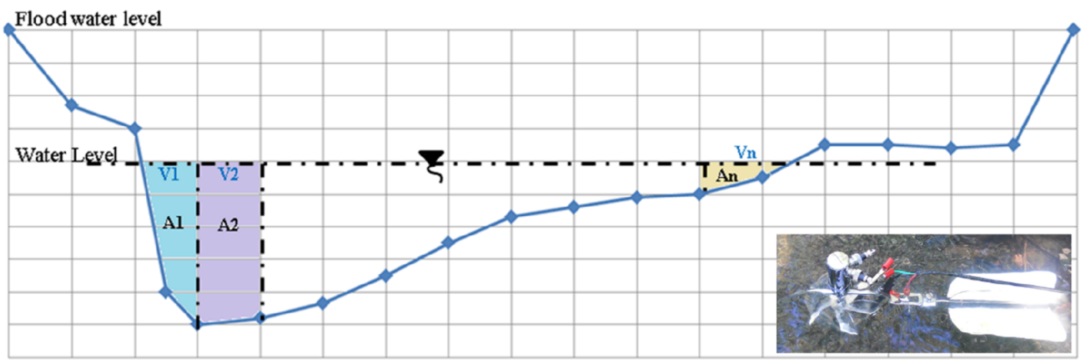


Figure 3: Stream Gauging (Area velocity method)

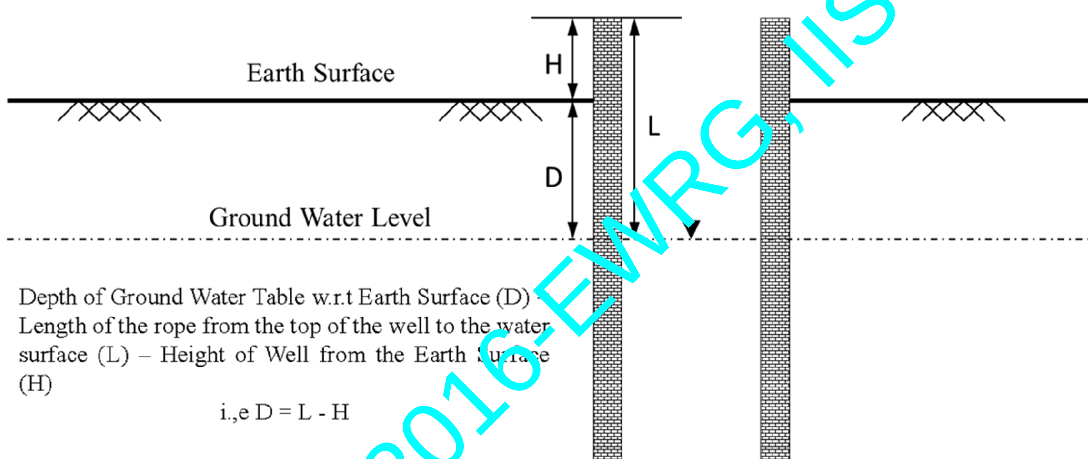
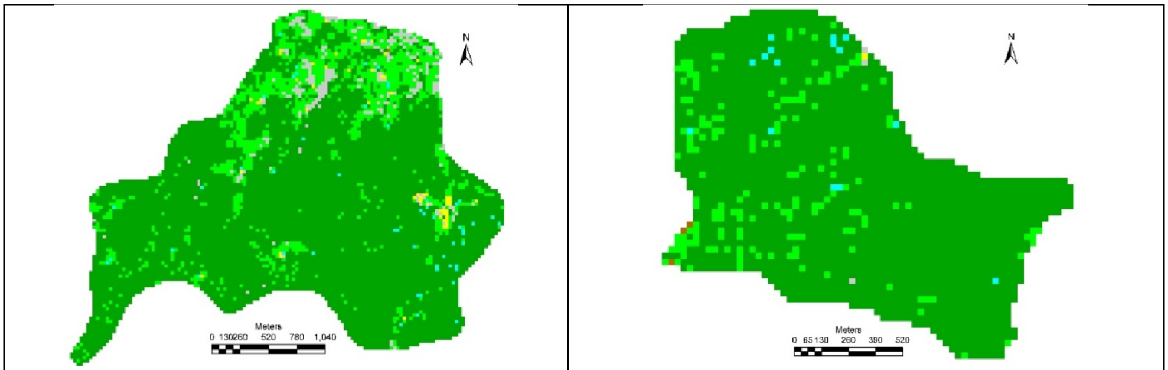


Figure 4: Measuring Ground water

RESULTS AND DISCUSSIONS

Land use analysis was carried out for the year 2016, and Hydrological analysis was carried out for each of the select catchment between July 2014 to April 2016. Results of the hydrological regime and land use for each pair of catchments are as presented in the subsections

(1) **Vibuthi and Mabgi:** Both these catchments are dominated by evergreen forests (Figure 5 and Table 2). Vibuthi has higher presence of few undisturbed evergreen forests, whereas Mabgi is completely secondary evergreen forest. The hydrological analysis reveals that presence of undisturbed forest in the catchment, yield higher water during the post monsoons, whereas higher infiltration during the monsoons. This could be observed in Mabgi where in there is higher discharge during monsoons with average 86.28 mm/day during monsoons against vibuthi with 60.47 mm/day, during the summer seasons Mabgi stream dries up with average flow 0.12 mm/day for 11 months, whereas Vibuthi stream is perennial and yields 0.9 mm/day (Figure 6). Even during the low monsoons Vibuthi showed higher water yield. Vibuthi due to higher depth of soils in the substrata has the ability to store water during the monsoons (higher infiltration) and gradually release during the non-monsoon seasons, whereas Mabgi has lower soil depths with granitic rocks in the forests which has lower infiltration potential, hence higher yield during the monsoon season.



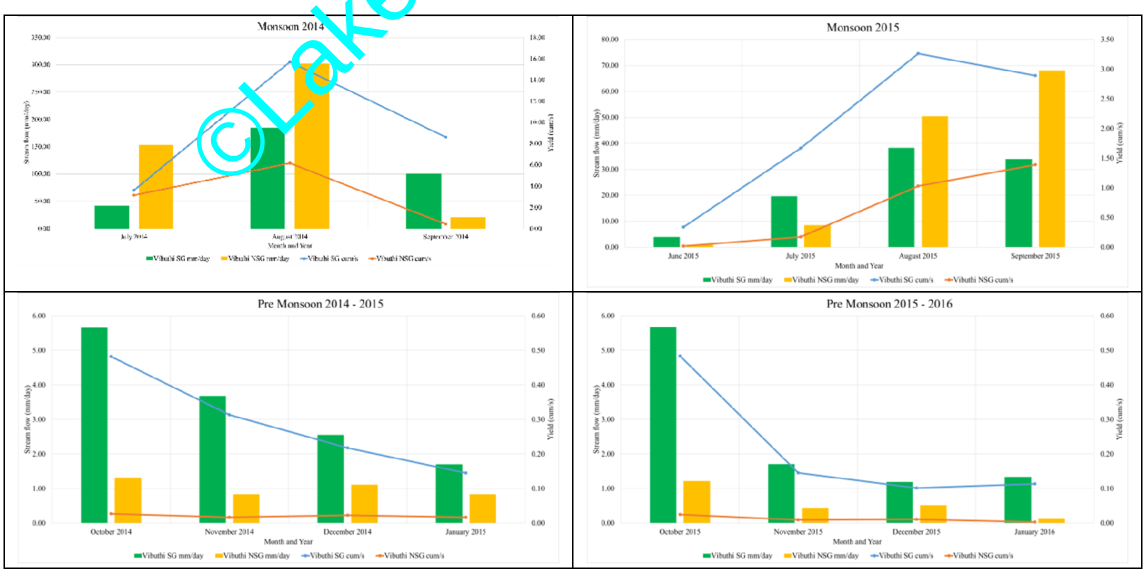
Vibuthi SG	Mabgi - Vibuthi NSG

Legend: Water, Evergreen Forest, Deciduous Forest, Forest Plantation, Horticulture, Agriculture, Grassland/Open/Rock outcrop

Figure 5: Land use of Vibuthi SG and Mabgi NSG

Table 2: Land use of Vibuthi and Mabgi

Catchment	Vibuthi SG		Mabgi NSG	
	Area in Ha	Area %	Area in Ha	Area %
Water	0.00	0.00	0.00	0.00
Horticulture	3.85	0.51	1.03	0.54
Open/Grass/Rock outcrop	22.54	3.01	0.21	0.11
Evergreen Forest	605.42	80.93	178.59	92.96
Deciduous Forest	111.42	14.89	11.98	6.24
Agriculture	4.74	0.63	0.09	0.05
Forest Plantation	0.09	0.01	0.21	0.11
	748.06		192.12	



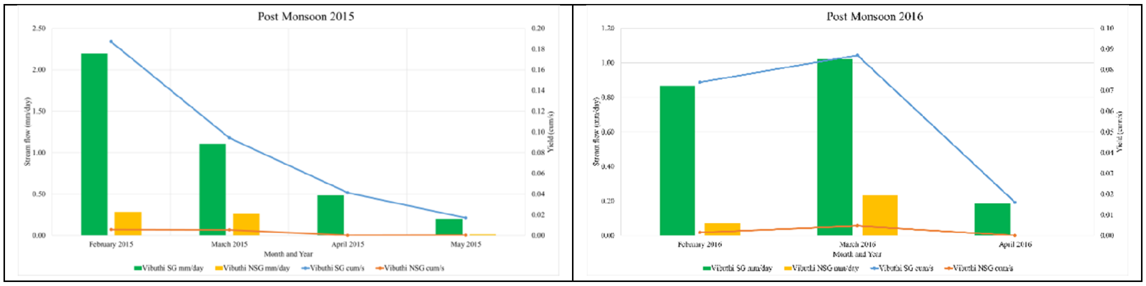


Figure 6: Stream flow dynamics in Vibuthi and Mabgi

(2) **Yaana and Nanalli:** Yaana and Nanalli catchments are dominated by evergreen forest patches with 92.16 and 94.93% evergreen forest cover respectively (Figure 7 and Table 3). Hydrological analysis of Yaana nad Nanalli (Figure 8) revels that Yaana and Nanalli catchments have similar behavior in the pre monsoons with average yield of 0.75 mm/day. Yaana catchment showed higher levels of infiltration during the monsoons (yield 75.1 mm/day), whereas the Nanalli had higher runoff yield (117.23 mm/day) in the monsoons, Whereas during the post monsoons Yaan had higher yield about 6.65 mm/day compared to Mabgi with yield of 3.29 mm/day.

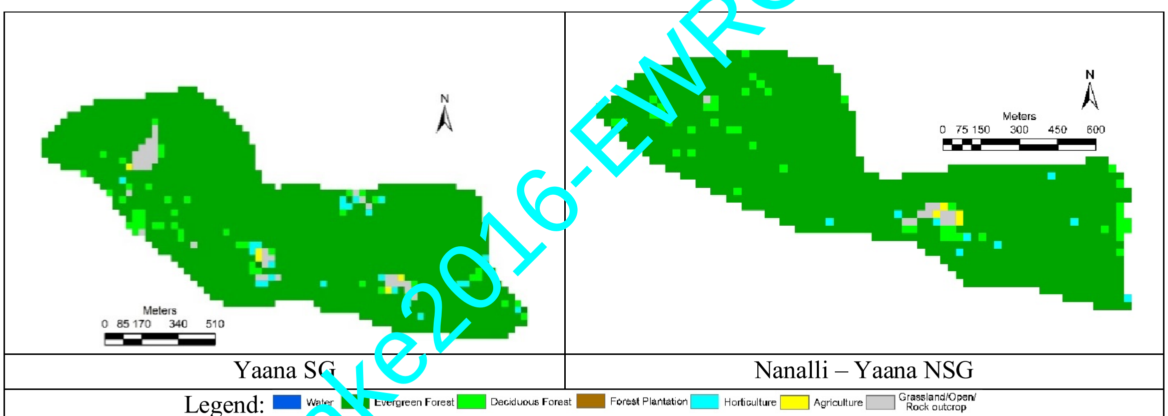


Figure 7: Land use of Yaana SG and Nanalli NSG

Table 3: Land use of Yaana and Nanalli

Catchment	Yaana SG		Nanalli NSG	
	Area in Ha	Area %	Area in Ha	Area %
Water	0.00	0.00	0.00	0.00
Horticulture	2.07	1.57	0.58	0.60
Open/Grass/Rock outcrop	3.60	2.73	0.95	0.98
Evergreen Forest	121.59	92.16	91.63	94.93
Deciduous Forest	4.23	3.21	3.06	3.17
Agriculture	0.45	0.34	0.31	0.32
Forest Plantation	0.00	0.00	0.00	0.00
	131.94		96.53	

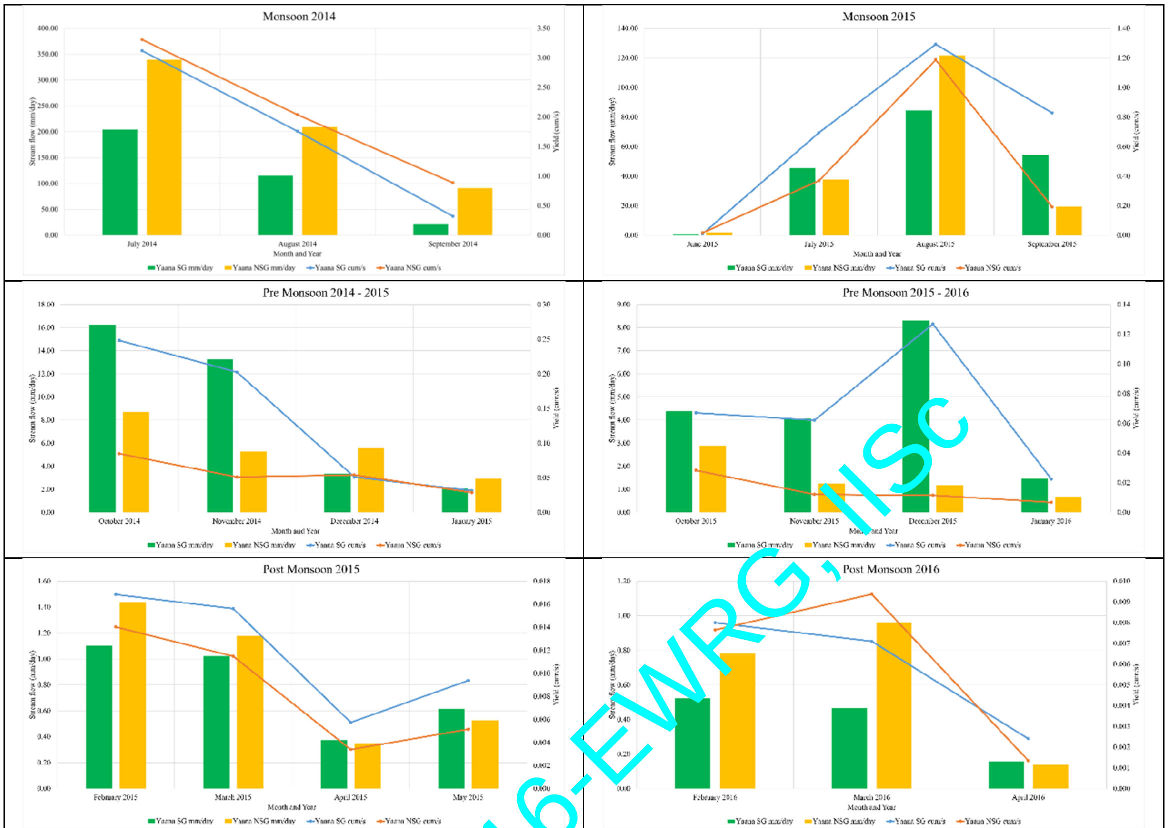
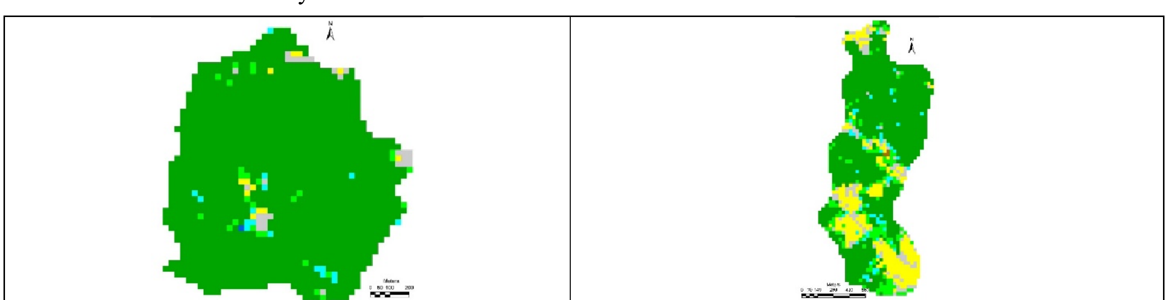


Figure 8: Stream Flow dynamics in Yaana SG and Nanalli NSG

(3) **Kathlekan and Kodkani:** Kathlekan as the name specifies it is dark forest, where is the catchment is completely covered by evergreen forest i.e., about 94.35%, these forests have little or no anthropogenic activities, whereas Kodkani is affected by human activities, about 20% of the total area is under agriculture and horticultural activities, and the forest area is about 72.8% (Figure 9 and Table 4, Table 5). Hydrological investigations (Figure 10, Figure 11) at Kathlekan was carried out at 5 different places, and 2 places at Kodkani. In the study 2 locations of Kathlekan and one location of Kodkani is presented. Presence of undisturbed forest in the catchments is clearly demonstrated by Kathlekan i.e., Kathlekan streams showed higher yield in all seasons compered to Kodkani. This can be attributed to the soil characteristics for higher yield in monsoon and vegetation characteristics/abilities during the post monsoons. Several other studies showing rich biodiversity in Kathlekan [37] which can be directly related to the presence water creating suitable habitats.



Kathlekan SG | Kodkani - Kathlekan NSG

Legend: Water, Evergreen Forest, Deciduous Forest, Forest Plantation, Horticulture, Agriculture, Grassland/Open/Rock outcrop

Figure 9: Land use of Kathlekan SG and Kodkani NSG

Table 4: Land use of Kathlekan/Kattalekan L5 and Kodkani

	Kathlekan SG L5		Kodkani NSG	
Catchment	Area in Ha	Area %	Area in Ha	Area %
Water	0.09	0.07	0.00	0.00
Horticulture	1.17	0.94	5.03	3.29
Open/Grass/Rock outcrop	2.16	1.74	10.02	6.55
Evergreen Forest	117.18	94.35	98.45	64.34
Deciduous Forest	1.98	1.59	13.06	8.54
Agriculture	1.62	1.30	26.16	17.10
Forest Plantation	0.00	0.00	0.29	0.19
	124.20		153.01	

Figure 10: Stream Flow dynamics in Kathlekan SG L5 and Torme NSG

Table 5: Land use of Kathlekan L2 and Kodkani

	Kathlekan SG L2		Kodknai NSG	
Catchment	Area in Ha	Area %	Area in Ha	Area %
Water	0.00	0.00	0.00	0.00
Horticulture	0.00	0.00	5.03	3.29
Open/Grass/Rock outcrop	0.42	3.71	10.02	6.55
Evergreen Forest	10.75	95.26	98.45	64.34

Deciduous Forest	0.00	0.00	13.06	8.54
Agriculture	0.12	1.03	26.16	17.10
Forest Plantation	0.00	0.00	0.29	0.19
	11.28		153.01	

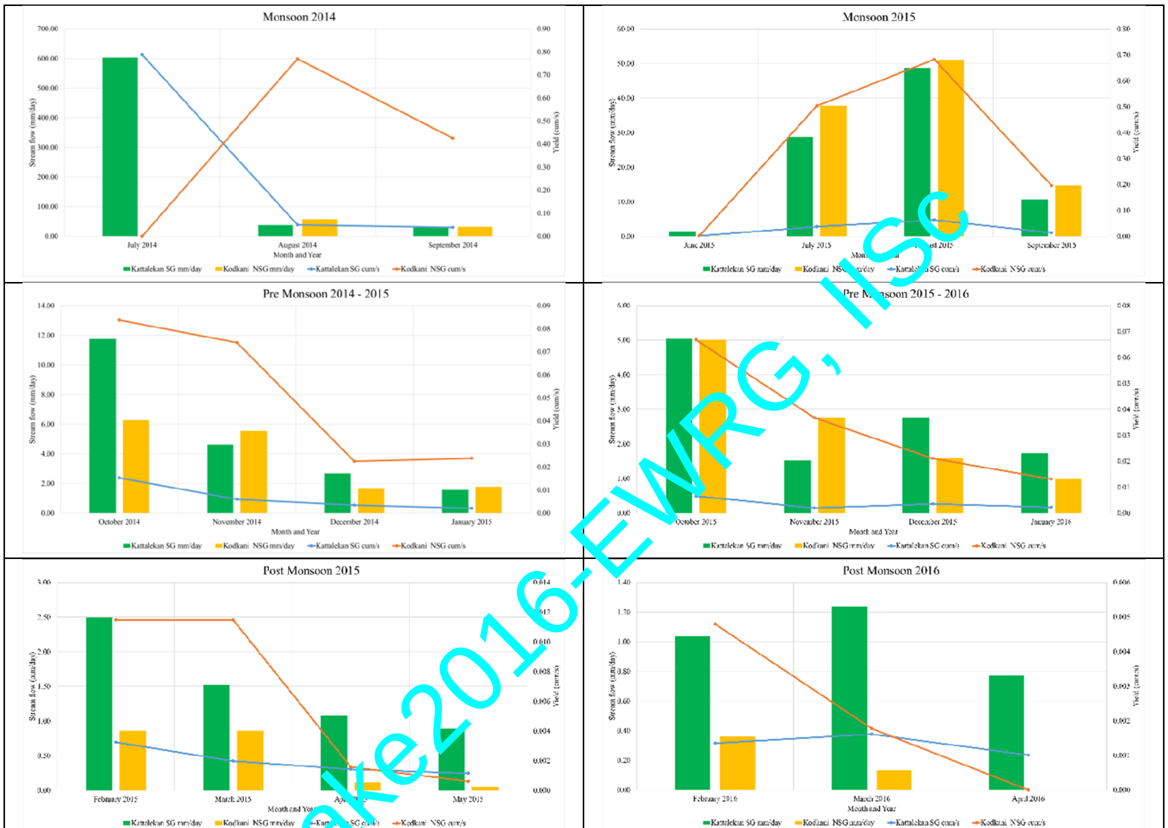


Figure 11: Stream Flow dynamics in Kathlekan SG L2 and Torme NSG

(4) **Torme and Kanalli:** Torme and Kanalli are dominated with evergreen forest patches, i.e., 92.13% and 82.23% respectively (Figure 12 and Table 7). Kanalli with due course of time (based on field knowledge) is affected by anthropogenic activities, i.e., cutting of forest for fire wood, laying electrical lines for pumping water etc. At torme, hydrological analysis was carried out on streams (Figure 13), whereas at Kanalli since the catchment was altered, stream flow was completely dependent on the water released/pumped for irrigation due to which hydrological analysis was carried on the irrigation pond (Figure 14). Steam flow analysis at Torme indicated that compared to any other SG's, it had higher water yield during the lean seasons. The analysis of pond shoed that typically, it is at the highest level between July and October, whereas it starts dropping down in the post monsoons and observed to be minimum in the months of April, May and June. It could be observed that, during the low monsoon seasons (2015 – 2016), maximum water level was observed only during July and August and the water level has dropped to the lowest by April 2016 (against April 2015).

Table 7: Land use of Torme and Kanalli

Catchment	Torme SG		Kanalli NSG	
	Area in Ha	Area %	Area in Ha	Area %
Water	0.00	0.00	0.00	0.00
Horticulture	0.68	1.36	0.22	2.52
Open/Grass/Rock outcrop	2.74	5.49	0.43	4.87
Evergreen Forest	45.97	92.13	7.29	83.23
Deciduous Forest	0.45	0.90	0.40	4.55
Agriculture	0.06	0.12	0.36	4.15
Forest Plantation	0.00	0.00	0.06	0.68
	49.90		8.76	

Torme SG | Kanalli – Torme NSG

Legend: Water, Evergreen Forest, Deciduous Forest, Forest Plantation, Horticulture, Agriculture, Grassland/Open/Rock outcrop

Figure 12: Land use of Torme SG and Kaanalli NSG

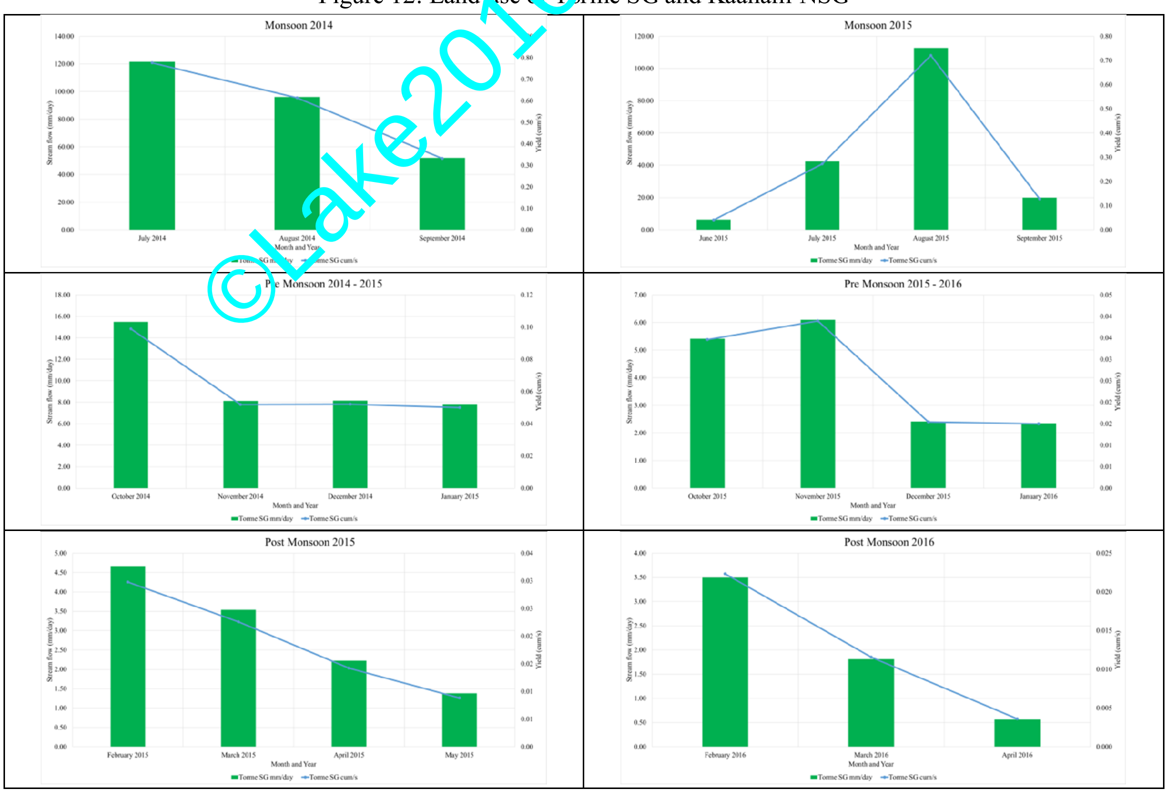


Figure 13: Stream Flow dynamics in Torme SG

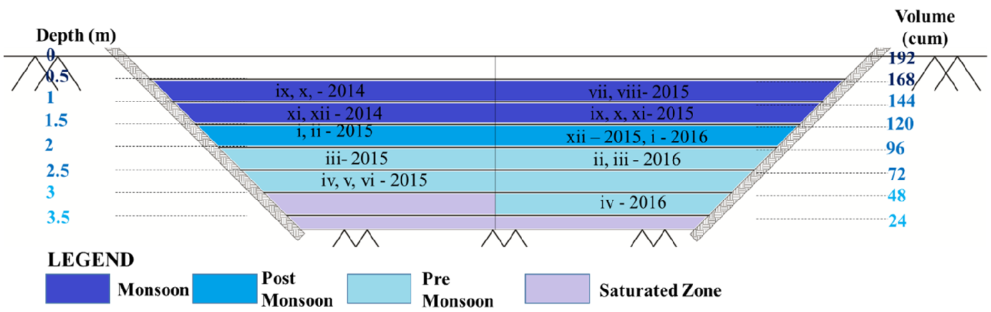


Figure 14: Pond water dynamics in Kanalli NSG

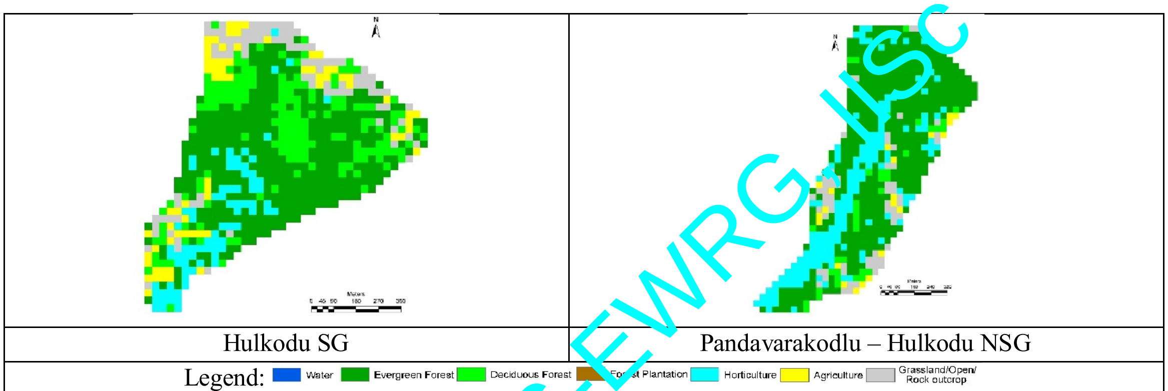


Figure 15: Land use of Hulkodu SG and Pandavarakodlu NSG

Table 8: Land use of Hulkodu and Pandavarakodlu

Catchment	Hulkodu SG		Pandavarakodlu NSG	
	Area in Ha	Area %	Area in Ha	Area %
Water	0.00	0.00	0.00	0.00
Horticulture	7.08	10.04	14.15	21.75
Open/Grass/Rock outcrop	8.29	11.75	5.44	8.36
Evergreen Forest	34.82	49.37	40.60	62.40
Deciduous Forest	14.32	20.31	3.08	4.73
Agriculture	6.02	8.53	1.80	2.76
Forest Plantation	0.00	0.00	0.00	0.00
	70.53		65.06	

(5) **Hulkodu and Pandavarakoldu:** Hulkodu and Torme have mixed land uses (Figure 15, Table 8). Similar to Torme and Kanalli, Stream flow (Figure 16) was measured at Hulkodu (catchment area 10 hectares upstream) and Pandavarakodlu with irrigation pond/lake (Figure 17), followed by wells in the downstream (Figure 18). Bathymetric analysis was carried in Pandavarakodlu and is as depicted in Figure 17. Hulkodu stream was found to be perennial with presence of swamps. Lake assessment in Pandavarakodlu indicated that the lake was controlled for irrigation purposes, water was allowed to flow out of the tank during the rainy seasons, and stored during the final monsoons (September, October) and slowly released during the post monsoons. Presence of evergreen forest cover in the upstream of the lake is the major contributing factor for the lake during the post monsoons.

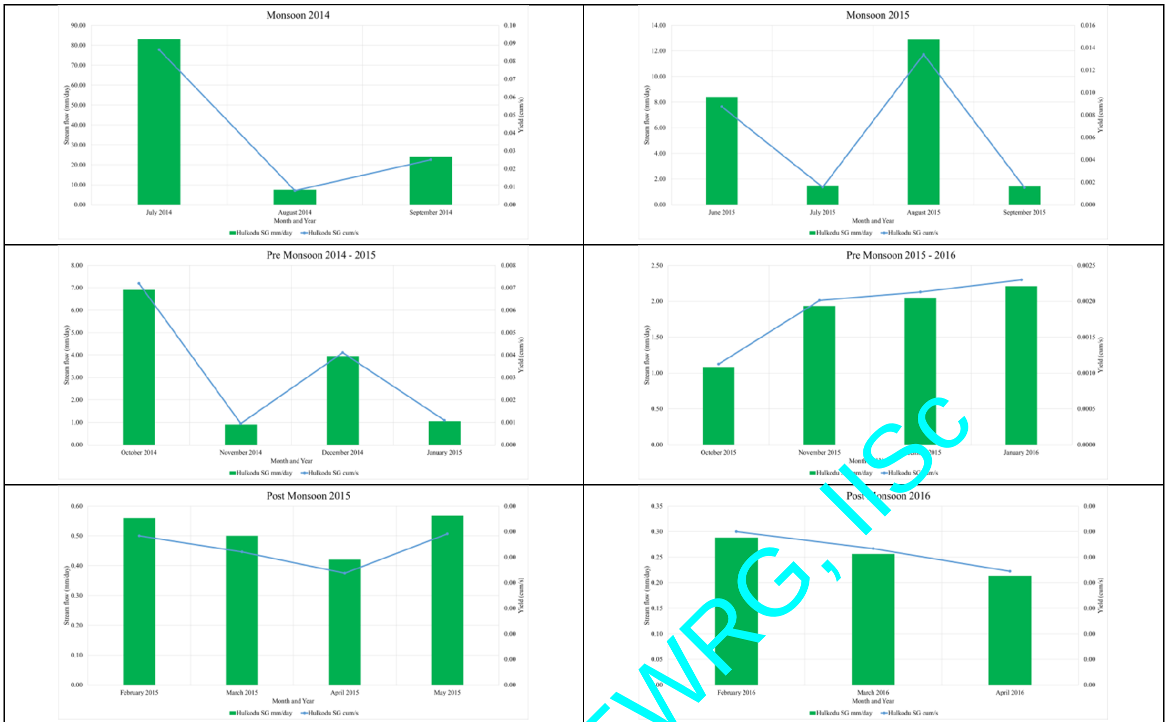


Figure 16: Stream flow dynamics in Hulkodu SG

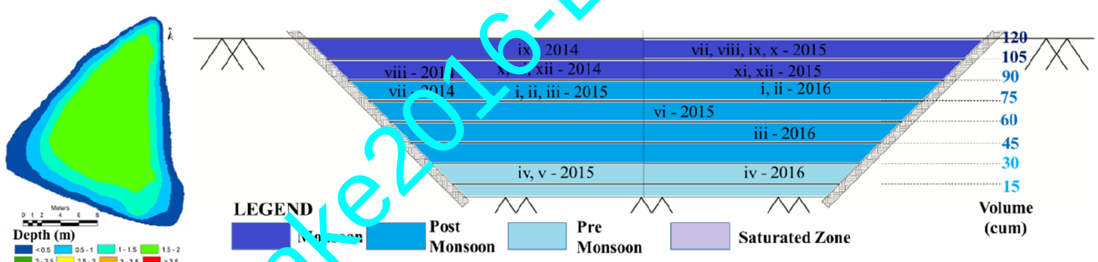


Figure 17: Bathymetry and Lake water dynamics in Pandavarakodlu

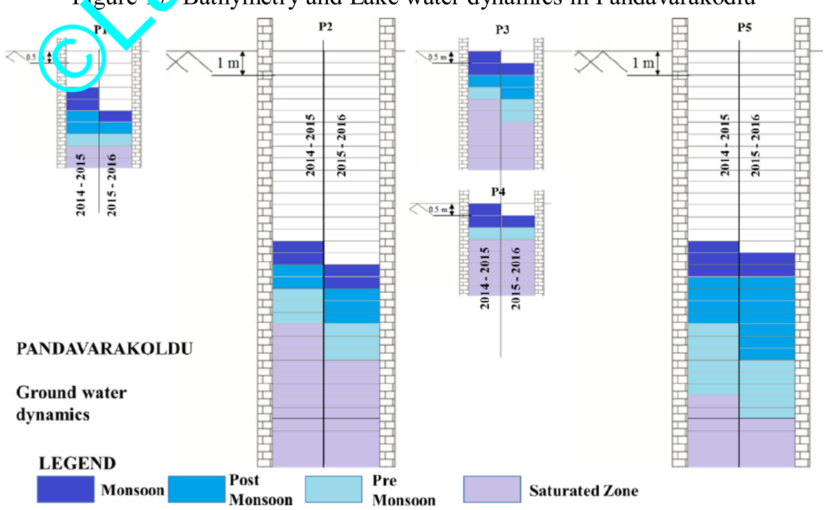


Figure 18: Ground Water dynamics in Pandavarakoldu

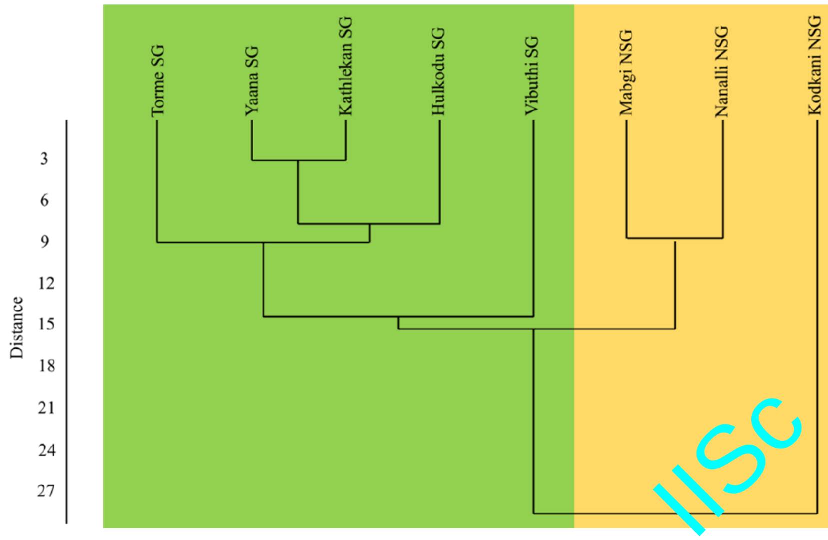


Figure 19: Stream Flow Cluster Diagram

Cluster analysis (figure 19) was carried out to understand the similarity in hydrological regime of streams between catchment, using various parameter namely Evergreen forest cover as %, Evergreen ness %, Species Richness, Winter Flow, Summer Flow, Flow duration (months), Bulk Density, Moisture Content. The cluster analysis indicated that the catchments consisting sacred groves and non-sacred groves are forming two different clusters. Yaana and Kathalekan Sacred Groves shows closer association, similarly in the non-SG, Mabgi and Nanalli shows closer associations. Closer associations indicating higher similarities between catchments.

CONCLUSION

Hydrological assessment in the 7 pairs of catchments in Western Ghats emphasizes the role of both natural and relic forests aiding in sustainable fresh water availability in streams and rivers throughout the year compared to the degraded catchments which are seasonal. Stream with sacred groves were found to satisfy the minimum flow criteria i.e., 30% of the annual flow (Tennant's method 1975 [38]). Presence of native vegetation in the catchments enhanced the infiltration and water holding capabilities of the catchments. This was supported by studies carried on ground water, where in table were relatively high near the sacred groves with less variability across seasons (< 0.6 m) and streams had higher yield i.e., over 5 times in catchments consisting sacred forests against other catchments. The lakes/tanks were perennial with higher water yield in case of catchment consisting natural forests (Pandavarakodalu, Kanalli). Cluster analysis emphasizes on the role natural forests (various characteristics) influencing water availability in catchments. The study emphasizes on the role natural forests influencing water availability in catchments that would help in planning sustainable watershed management programs.

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