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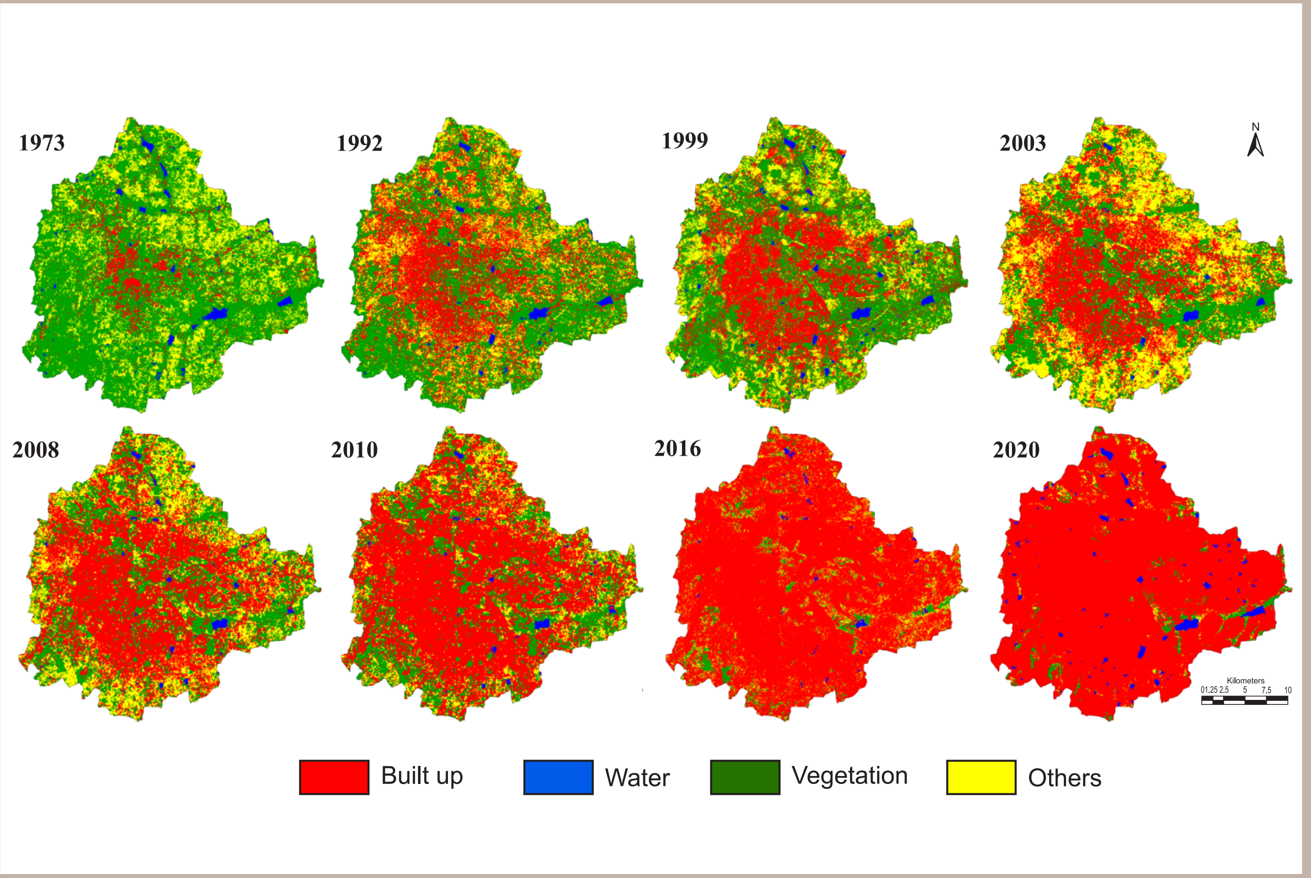

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GUEST EDITORIAL

Bengaluru's reality: towards unlivable status with unplanned urban trajectory

The origin of cities can be traced back to the river valley civilizations of Mesopotamia, Egypt, Indus Valley and China. Initially these settlements were largely dependent upon agriculture; however, with the growth in population the city size increased and economic activity transformed to trading (Ramachandra, T. V. *et al.*, *TEMA J. Land Use, Mobility Environ.*, 2014, **7**(1), 83–100). The process of urbanization gained impetus with the Industrial Revolution 200 years ago and accelerated in the 1990s with globalization and consequent relaxation in market economy (Ramachandra, T. V. *et al.*, *Int. J. Appl. Earth Obs. Geoinf.*, 2012, **18**, 329–343).

Urbanization refers to the growth of towns and cities due to large proportion of the population living in urban areas and its suburbs at the expense of rural areas (*op. cit*). In most of the countries, the total population living in urban regions has extensively accelerated since the Second World War. Rapid urbanization is evident from the increase in global urban population from 13% (220 million) in 1900 to 49% (3.2 billion) in 2005, and is expected to increase to 60% (4.9 billion) by 2030 (*op. cit*). Current global population is 7.4 billion and urban population has been increasing three times faster than the rural population, mainly due to migration in most parts of the world. People migrate to urban areas with the hope of better living, considering relatively better infrastructural facilities (education, recreation, health centres, banking, transport and communication), and higher per capita income. Unplanned urbanization leads to the large-scale land-use changes affecting the sustenance of local natural resources. Rapid unplanned urbanization in most cities in India has led to serious problems in urban areas due to higher pollution (Ramachandra, T. V. *et al.*, *Renew. Sustain. Energy Rev.*, 2015, **44**, 473–495) (air, water, land, noise), inequitable distribution of natural resources, traffic congestion, spread of slums, unemployment, increased reliance on fossil fuels, and uncontrolled outgrowth or sprawl in the periphery. Understanding spatial patterns of urban growth and visualization is imperative for sustainable management of natural resources and to mitigate changes in climate. This would help the city planners to mitigate the problems associated with the increased urban area and population, and ultimately build sustainable cities.

Bengaluru is experiencing unprecedented rapid urbanization and sprawl in recent times due to unrealistic concentrated developmental activities with impetus on industrialization for the economic development of the region. This has led to large-scale land-cover changes with serious environmental degradation, posing serious challenges to the decision makers in the city planning and management process, such as climate change, enhanced emissions of greenhouse gases (GHGs), lack of appropriate infrastructure, traffic congestion, and lack of basic amenities (electricity, water and sanitation) in many localities. Apart from these, major implications of urbanization are the following.

Urbanization and loss of natural resources (wetlands and green spaces): Urbanization during 1973–2016 (1005% concretization or increase of paved surface) has had a telling influence on the natural resources, such as decline in green spaces (88% decline in vegetation), wetlands (79% decline), higher air pollutants and sharp decline in groundwater table. Figure (see Cover Page of this issue) depicts the unrealistic urban growth during the last four decades. Quantification of the number of trees in the region using remote sensing data with field census reveals that there are only 1.5 million trees to support Bengaluru's population of 9.5 million, indicating one tree for every seven persons in the city (Ramachandra, T. V. *et al.*, *ENVIS Technical Report 75*, IISc, 2014, p. 75). This is insufficient even to sequester respiratory carbon (ranges from 540 to 900 g per person per day). Geo-visualization of likely land uses in 2020 through multi-criteria decision-making techniques (Fuzzy-AHP) reveals a calamitous picture of 93% of Bengaluru's landscape being filled with paved surfaces (urban cover), and drastic reduction in open spaces and green cover. This would make the region GHG-rich, water-scarce, non-resilient and unlivable, depriving the city-dwellers of clean air, water and environment.

Field studies during 2015–16 of 105 lakes revealed that 98% of the lakes have been encroached for illegal buildings (high-rise apartments, commercial buildings, slums, etc.) and 90% of the lakes are sewage-fed. Also, lake catchments are being used as dumping yards for either municipal solid waste or building debris. Indiscriminate disposal of solid and liquid waste (rich in organic nutrient) has enriched nitrate levels in the surrounding groundwater resources, threatening the health of residents (such as kidney failure, cancer, etc.). Washing, household activities, vegetable cultivation and even fishing was observed in few contaminated lakes. Unauthorized construction in valley zones, lakebeds and storm water drains highlight the apathy of decision-makers, while mirroring weak and fragmented governance. This is correlated with the increase in unauthorized constructions violating town planning norms (city development plan), which has severely affected open spaces and water bodies in particular.

Large-scale fish mortality in recent months further highlights the level of contamination and irresponsible management of water bodies. Sustained inflow of untreated sewage has increased the organic content beyond the threshold of remediation capability of the respective water bodies. Increasing temperatures (34–35°C) with the onset of summer, enhanced the biological activities (evident from higher ammonia and biochemical oxygen demand) that lowered dissolved oxygen levels leading to fish death due to asphyxiation.

Floods: Conversion of wetlands to residential and commercial layouts has compounded the problem by removing the interconnectivities in an undulating terrain. Encroachment of natural drains, alteration of topography involving the construction of high-rise buildings, removal of vegetation cover, and reclamation of wetlands are the prime reasons for frequent flooding even during normal rainfall post 2000.

Decline in groundwater table: The water table has declined to 300 m from 28 m, and 400–500 m in intensely urbanized area such as Whitefield, over a period of 20 years.

Heat island: Surface and atmospheric temperatures have increased due to the loss of natural cover (trees and water bodies) with an increase in artificial materials having high heat conductivities. Temperature has increased by ~2–2.5°C during the past three decades, highlights the implications of explosive urban growth on local climate, necessitating appropriate mitigation strategies.

Increased carbon footprint: Drastic increase in electricity consumption has been observed in certain corporation wards due to adoption of inappropriate building architecture in tropical climate. Per capita electricity consumption in the zones dominated by high-rise building with glass facades ranges from 14,000 to 17,000 units (kWh) per year compared to zones with eco-friendly buildings (1300–1500 units/person/yr)[3].

Emissions from the transport sector is about 43.83% (in Greater Bengaluru) on account of large-scale usage of private vehicles, and mobility related to job accounts for 60% of total emissions due to lack of appropriate public transport system and haphazard growth with unplanned urbanization. Majority commute longer distances with private vehicles, thus contributing to emissions. Apart from these, mismanagement of solid and liquid waste has aggravated the situation with emission of GHGs (methane, CO_2, etc.)

Unplanned cities thus not only contribute to global climate change by emitting the majority of anthropogenic GHGs but are also particularly vulnerable to the effects of climate change and extreme weather. This emphasizes the need to improve urban sustainability through innovations while addressing technical, ecological, economic, behavioural and political challenges to create cities that are low-carbon, resilient and livable.

The 'Smart Cities Mission' launched by the Government of India recently (June 2015) envisages developing physical, institutional and social infrastructure in select cities with central assistance targeted at improving the quality of life as well as economic visibility of the respective urban centres (http://smartcities.gov.in/ (last accessed on 20 May 2016)). Four strategic components are: (i) green field development through smart townships by adopting holistic land management; (ii) pan-city development through adoption of smart applications like transport, reuse and recycle of wastewater, smart metering, recovering energy from solid waste, etc. (iii) retrofitting to make existing areas more efficient and livable by reducing GHG footprint, improving power and treated water supply, improving communication and infrastructure connectivity and security, and (iv) re-development of existing built-up area, creation of new layouts through mixed land use, adoption of appropriate floor area index considering the level of existing, and scope for improvement of infrastructure and basic amenities, which helps in keeping the city's growth within the region's carrying capacity, and also urban infrastructure becomes inclusive. This entails efficient decision-making through (i) integrated land-use planning according to the city's requirements; (ii) enhancement of the functional capacity through user-friendly and economic public transport support; (iii) development of mass rapid-transport systems, and (iv) effective use of ICTs as enabling technologies. These measures have to be implemented quickly as most cities are in a civic and financial disarray because of senseless unplanned rapid urbanization.

Environmentally sound urban centres with essential basic amenities and advanced infrastructure (such as sensors, electronic devices and networks) would stimulate sustainable economic growth and improvements in citizen services. The effective and coordinated governance supports social and urban growth through improved economy and active participation of citizens. Indian cities, while exhibiting technological innovations and connectedness, should also focus on increased living comfort through adequate infrastructure, green spaces and essential basic amenities to every citizen.

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Research Article Open Access

Environmental Flow Assessment in a Lotic Ecosystem of Central Western Ghats, India

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Abstract

Environmental/Ecological flow refers to the minimum flow of water to be maintained in a water body (river, lake, etc.) to sustain ecosystem services. Understanding environmental flow is important to ensure the local ecological and social (people, agriculture and horticulture, etc.) needs in a sustained and balanced way, while designing large scale projects (such as hydro-electric, river diversion, etc.). Western Ghats are the mountain ranges extending from southern tip of India (Tamil Nadu-Kanyakumari) to Gujarat. These mountain ranges are rich in biodiversity with diverse and endemic flora and fauna, and is birth place to numerous perennial rivers namely Netravathi, Sita, Sharavathi, Aghanashini, Krishna, Cauvery, etc. Western Ghats is often referred as water tower of peninsular India, due to the water and food security provided by the ecosystem through array of services. The region is also one among 35 global biodiversity hotspots. However, deforestation due to large scale land cover changes has affected the water sustenance in the region evident from the quantity and duration of water availability during post monsoon period. Forests in the Western Ghats along with the soil characteristics and precipitation plays a major role in storing water in sub-surface (vadoze and groundwater) zones during monsoon, and releases to the streams during post monsoon periods catering to the needs of the dependent biota including humans. Some of these undisturbed/ unaltered natural flow conditions in rivers and streams have proved their worth with the presence of rich and diverse species and array of ecosystem services, which also has helped in sustaining the livelihood of dependent populations. The undisturbed flow conditions guarantees the natural flow as well as minimum flow in streams to sustain the ecosystem services, which helps in meeting the social and ecological needs. Growing demand to cater the demands of burgeoning human population coupled with accelerated pace of deforestation due to unplanned and senseless developmental projects in the ecologically fragile regions have led the water scarcity even in regions receiving high amount of rainfall. In the current communication an attempt is made to understand the linkages between the hydrological dynamics across varied landscape with the anthropogenic and ecological water needs. If the available water resource meets the societal and environmental demands across seasons, the catchment is said to achieve the minimum flow requirements. The federal government has plans to divert the water from rivers in Western Ghats region to the dry arid regions in Karnataka. In this regard, environmental flow assessment of Yettinaholé river in Central Western Ghats is carried out to understand the feasibility of river diversion through the assessment of hydrologic regime with the analysis of land use dynamics (using remote sensing data), meteorological data (rainfall, temperature, etc. from IMD, Pune), hydrological data (from gauged streams) apart from field investigations in the catchment. The catchments receive annual rainfall of 3000-5000 mm (Department of Statistics, Government of Karnataka). Land use analyses reveal that Major portion of the catchment is covered with evergreen forest (45.08%) followed by agriculture plantations (29.05%) and grass lands (24.06%). Water yield in the catchment computed for each of sub-catchments based on the current land use and other related hydrological parameters using empirical method. The total runoff yield from the catchments is estimated to be 9.55 TMC. About 5.84 TMC is required for domestic purposes including agriculture, horticulture and livestock rearing. The quantum of water required to sustain fish life in the streams is about 2 TMC, computed based on hydrological discharge monitoring and fish diversity in streams during 18 months (covering all seasons) in select streams in Western Ghats. Considering the available water is sufficient only to meet the anthropogenic and ecological needs in the region, the sustainable option to meet the water requirements in dry arid regions would be through (i) decentralized water harvesting (through tanks, ponds, lakes, etc.), (ii) rejuvenation or restoration of existing lakes/ponds, (iii) reuse of waste water, (iv) recharging groundwater resources, (v) planting native species of grasses and tree species in the catchment (to enhance percolation of water in the catchment), (vi) implementation of soil and water conservation through micro-watershed approaches. Implementation of these location specific approaches in arid regions would cost much less compared to the river diversion projects, which if implemented would help the section of the society involved in decision making, construction and implementation of the project.

Keywords: Ecological flow; Yettinaholé River; Watershed; Land cover; Fresh water ecosystem

Introduction

The Western Ghats is a series of hills located in the western part of peninsular India stretching over a distance of 1,600 km from north to south and covering an area of about 1,60,000 sq.km and one among the

35 global hotspots of biodiversity [1-3]. It harbors very rich and rare flora and fauna and there are records of over 4,500 species of flowering plants with 38% endemics, 330 butterflies with 11% endemics, 156 reptiles with 62% endemics, 508 birds with 4% endemics, 120 mammals with 12% endemics, 289 fishes with 41% endemics and 135 amphibians with 75% endemics [4-7].

Western Ghats has numerous watersheds that feed perennial rivers of peninsular India [2]. It encompasses series of west and east flowing rivers that originates from the Western Ghats, supporting as source of sustenance for existing life forms in the environment. One such source of perennial waters is Yettinaholé originating at an altitude of 950 m in Sakaleshpura taluk of Hassan district, and tributary of river Gundia, which joins Kumaradhara and finally drains to Netravathi River The region with a repository of endemic and rare biodiversity is ecologically sensitive and large scale degradation of catchment landscape have influenced the availability of water and has also affected the sustenance of biodiversity. Changes in landscape structure and the regional climate [8,9] have altered the hydrologic regime [10,11] in many lotic ecosystems in the tropical regions, affecting the potential of the catchment to retain water in the surface and sub surfaces. Various studies carried out in Western Ghats [12-14] and across the globe show the relevance of landscape on surface and subsurface hydrological regime [12-19]. Few studies carried out in Western Ghats also emphasize on the role of hydrological regime on the habitats, ecology, biodiversity, quality of water, soil and ecosystem etc. [20-23]. In the current communication an attempt has been made to understand the linkages between the hydrological dynamics across varied landscape of Yettinaholé catchment with the societal and environmental water needs. In this regard, the study investigates land use dynamics, hydrological yield, fish diversity in select streams and linkages with the flow during lean season and drivers of hydrological regime impairment.

Materials and Methods

Study area

Yettinaholé catchment has a pristine ecosystem with rich biodiversity (Figure 1 and Table 1), extend from 12044'N to 12058'N Latitude and 75037'E to 75047'E longitude encompassing total area of 179.68 km^2. The terrain (Figure 2) is undulating with altitude varying from 666 m above MSL to 1292 m above MSL leading to higher density of stream network (Figure 3). Geologically, rock types consist of Gneiss, the soils are loamy ranging from sandy loamy to clay loamy. Soils (Figure 4) in the region are fertile and highly permeable, hence allowing the precipitated water to percolate easily into the subsurface recharging ground water and storing water in the sub surfaces and hence keeping the water source perennial to the catchment and the downstream users during and post monsoon.

Decadal population in Sakleshpura Taluk (spatial extent 1034 sq. km) of Hassan district is given in Figure 5 and Table 2 shows a declining trend due to migration to cities during post 2001. Population dynamics of the catchments also follows the dynamics of Sakleshpura taluk. Total Population of all the catchments with respect to census data [24,25] was estimated as 17005 in 2001, has declined to 16345 in 2011 at a decadal rate of 3.88%. Population for the year 2014 was calculated as 16156 based on the temporal data. Population density for each of the sub catchments are as depicted in Figure 6 and Table 3.

Sub basin id	Stream Name	Area (Ha)
1	Yettinaholé	4878.7
2	Yettinaholé T2	781.1
3	Yettinaholé T1	991.1
4	Kadumane holé 2	761.4
5	Kadumane holé 1	1362.4
6	Hongada halla	5676.6
7	Keri holé	2198.3
8	Yettinaholé lower reach	1319.1

Table 1: Study Area.

Census Year	1921	1931	1941	1951	1961
Population	44115	44300	43765	53398	77522
Census Year	**1971**	**1981**	**1991**	**2001**	**2011**
Population	91175	114008	124753	133657	128633

Table 2: Population Growth of Sakleshpura Taluk [24,25].

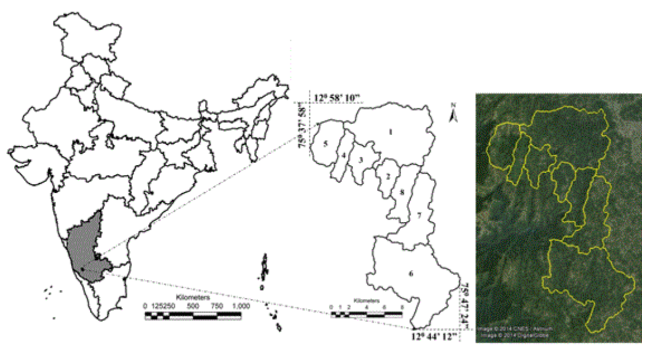

Figure 1: Study Area-Yettinaholé catchment, Karnataka, India.

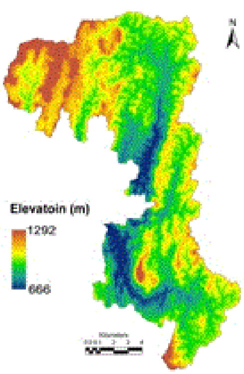

Figure 2: Digital Elevation Model.

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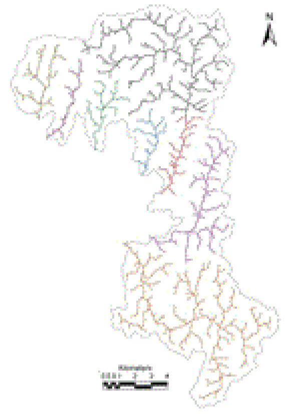

Figure 3: Stream Network.

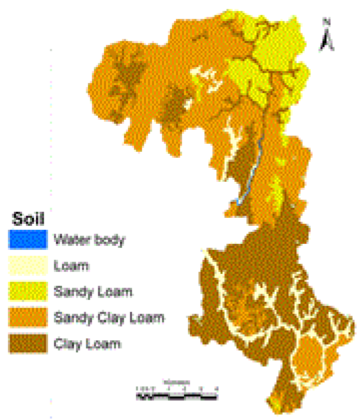

Figure 4: Soil.

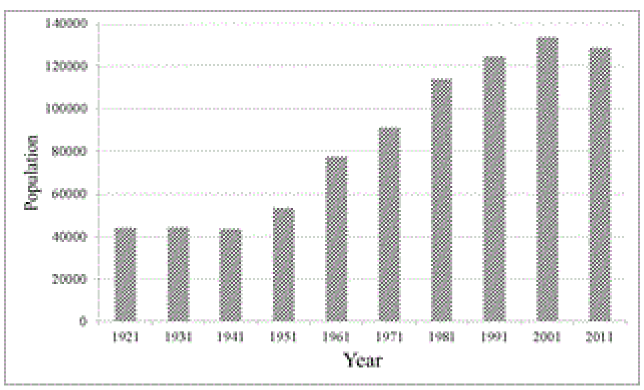

Figure 5: Population Growth of Sakleshpura Taluk.

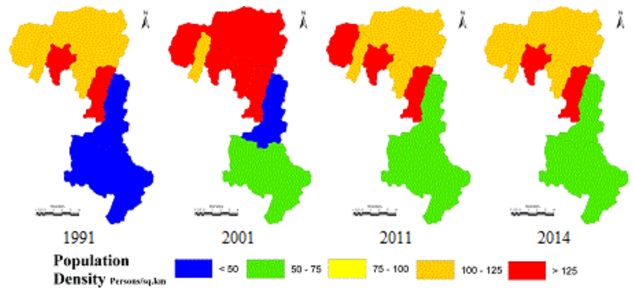

Figure 6: Population Density in Sub Catchments.

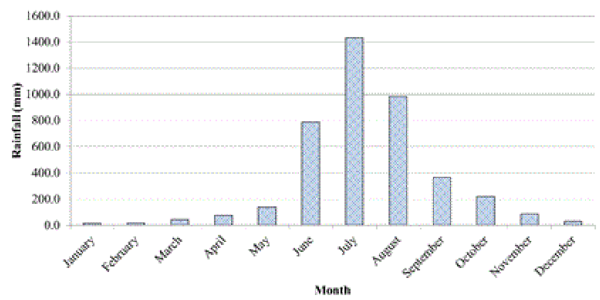

Figure 7: Rainfall in mm.

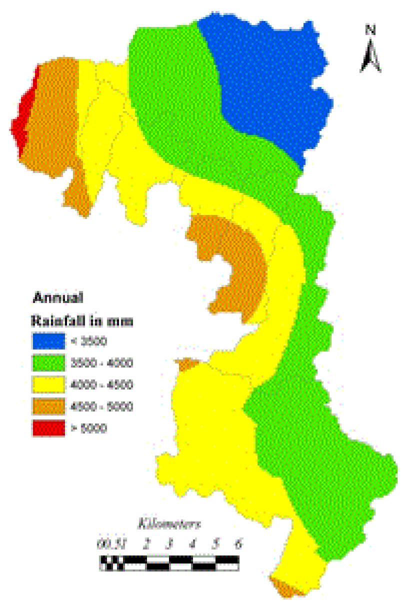

Figure 8: Rainfall distribution.

Sub Basin Id	Sub basin	1991	2001	2011	2014
1	Yettina holé	117.86	126.92	122	120.59
2	Yettina holé T2	116.12	125.08	120.22	118.81
3	Yettina holé T1	126.52	136.31	130.96	129.45
4	Kadumane holé 2	108.36	116.76	112.17	110.98
5	Kadumane holé 1	121.33	130.65	125.58	124.12
6	Hongadahalla	47.26	50.89	48.92	48.36
7	Keri holé	32.71	35.25	33.89	33.48
8	Yettina holé lower reach	151.46	163.14	156.85	155.03

Table 3: Population density (persons per sq. km).

The region receives an annual rainfall of 3500 to 5000 mm across the catchment. Precipitation in the catchment during June to September is due to the southwest monsoons, with July having maximum rainfall over 1300 mm. Monthly variation in rainfall is depicted in Figure 7. Spatial variation of rainfall across the catchments was assessed based on 110 years data [26] (1901 to 2010) from the rain gauge stations in and around the catchment (Figure 8). Figure 9 depicts monthly temperatures [27] variations, which ranges from 14.7°C (January) to 31.6°C (in March).

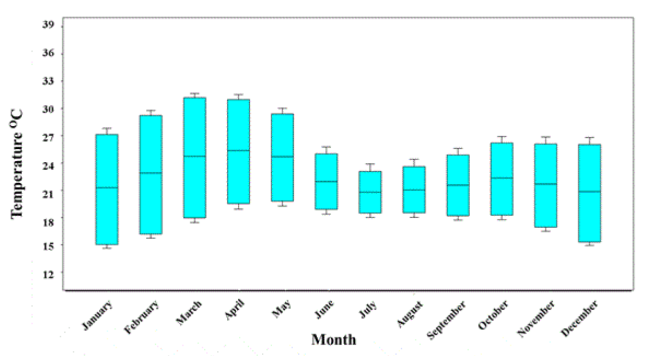

Figure 9: Monthly temperature variations.

Data

Data required for hydrological and land use analyses were (i) social and demographic data from the government agencies, (ii) temporal remote sensing data from public archive and (iii) primary data through field investigations. Latest remote sensing data used is of Landsat 8 series (2014). Rainfall data was acquired from the Directorate of Economics and Statistics, Government of Karnataka [26], Temperature data was sourced from World Clim-Global Climate Data [27] of 1 km resolution. Census data collected from government of India, state and district census departments [24,25]. These data was supplemented with secondary data compiled from various sources as tabulated in Table 4. Primary data is compiled through field investigations and through structured questionnaire (household survey).

Method

The method for the evaluation of the environmental flow and hydrological status is given in Figure 10. Hydrologic assessment in the catchment involved 1) delineation of catchment boundary 2) land use analysis, 3) assessment of the hydro meteorological data, 4) analysis of population census data, 5) compilation of data through public interactions for assessing the water needs for livestock, agriculture/ horticulture and cropping pattern, and 6) evaluation of hydrologic regime.

Delineation of catchment boundary: Catchment boundaries (Figure 1) and the stream networks (Figure 3) were delineated considering the topography of the terrain based on CartoSat DEM using the QSWAT module-Quantum GIS 2.10 32 bit. These catchment boundaries were overlaid on the extracted boundaries from the Survey of India topographic maps for validations. Corrected catchment boundaries were further overlaid on Google earth in order to visualize the terrain variations (Figure 2).

Data	Description	Source
Remote sensing data-spatial data	Remote sensing data of 30 m spatial resolution and 16 bit radiometric resolution were used to analyse land uses at catchment levels.	[28]
Rainfall	Daily rainfall data of 110 years (1901-2010), to assess the trends in rainfall distribution and variability across basins.	[26,29]
Crop Calendar	To estimate the crop water requirements based on the growth phases	[30-35]
Crop Coefficient	Evaporative coefficients used to estimate the actual evapotranspiration.	[33,36]
Temperature (max, min, mean), Extraterrestrial solar radiation	Monthly temperature data (1 km spatial resolution) and monthly extra-terrestrial solar radiation (Every 1° North latitude) available	[27,36-38]

	across different hemispheres to estimate the potential evapotranspiration.	
Population data	Population census data available at village level (2001, 2011), used to estimate the population at sub basin level for the year 2014, and estimate the water requirement for domestic use at sub basin levels.	[24,25]
Livestock Census	Taluk level data was used to estimate the livestock population and estimate water requirement at each of the river basins.	[39]
Digital Elevation data	Carto-DEM of 30 m resolution in association with Google earth and the Survey of India-Topographic maps (1:50000) was used to delineate the catchment boundaries, stream networks, contours, etc.	[40]
Secondary Data	Collateral data from government agencies regarding agriculture, horticulture, forests, soil, etc. for land use classification, delineation of streams/rivers/catchment, geometric correction (Remote sensing data).	[40-44]
Field data	Geometric Corrections, training data for land use classification, crop water requirement, livestock water requirement, etc.	GPS based field data, data form public (stratified random sampling of households)
Flow data	Evaluation of minimum flow requirements to sustain ecology (fish, etc.) and downstream dependent population's livelihood	Flow measurements at Hongadahalla, Kadumanehalla, and select streams of Sharavathi river [45,46]
Fish diversity	Understanding fish ecology in relation to water quantity and duration of flow to determine EF	Selected stream catchments and dams Sharavathi river [47]

Table 4: Data used for land use and assessment of hydrologic regime.

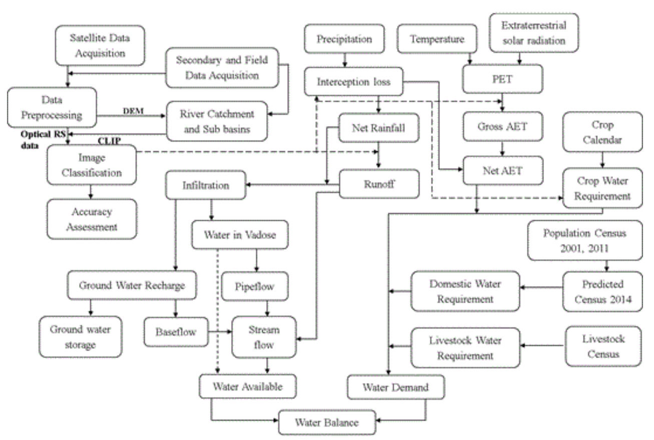

Figure 10: Method for computing environmental flow based on hydrologic variables.

Land use assessment: Large scale land-use land-cover (LULC) changes leading to deforestation is one of the drivers of global climate changes and alteration of biogeochemical cycles. This has given momentum to investigate the causes and consequences of LULC by mapping and modelling landscape patterns and dynamics and evaluating these in the context of human-environment interactions in the riverine landscapes. Human induced environmental changes and consequences are not uniformly distributed over the earth. However their impacts threaten the sustenance of human-environmental relationships. Land cover refers to physical cover and biophysical state of the earth's surface and immediate subsurface and is confined to describe vegetation and manmade features. Thus, land cover reflects the visible evidence of land cover of vegetation and non-vegetation. Land use refers to use of the land surface through modifications by humans and natural phenomena. Heterogeneous terrain in the landscape with the interacting ecosystems is characterized by its dynamics. Human induced land use and land cover (LULC) changes have been the major driver of the landscape dynamics at local levels. Land use assessment was carried using the maximum likelihood classification technique [48,49]. Understanding of landscape dynamics helps in the sustainable management of natural resources.

Land use analysis involved i) generation of FCC-False Colour Composite (Figure 11) of remote sensing data (bands-green, red and NIR). This helped in locating heterogeneous patches in the landscape ii) selection of training polygons (these correspond to heterogeneous patches in FCC) covering 15% of the study area and uniformly distributed over the entire study area, iii) loading these training polygons co-ordinates into pre-calibrated GPS, vi) collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, iv) supplementing this information with Google Earth v) 65% of the training data has been used for classification, while the balance is used for validation or accuracy assessment.

Land uses were categorized into 8 classes namely. i) water bodies (lakes/tanks, rivers, streams, ii) built up (buildings, roads or any paved surface, iii) open spaces iv) evergreen forest (evergreen and semi evergreen), v) deciduous forest (Moist deciduous and dry deciduous) vi) scrub land and grass lands, vii) agriculture, (viii) private plantations (coconut, arecanut, rubber) and forest plantations (Acacia, Teak, etc.)

Assessment of the hydro meteorological data: This involved assessment of the spatial and temporal variations in rainfall [26,29,50] in and around the study region. Long term precipitation data helped in understanding the rainfall variability over decades. Along with rainfall,

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temperature (minimum, maximum and average), extra-terrestrial solar radiation across the catchment were used to hydrological behaviors of the catchments which enables to understand the hydrological status.

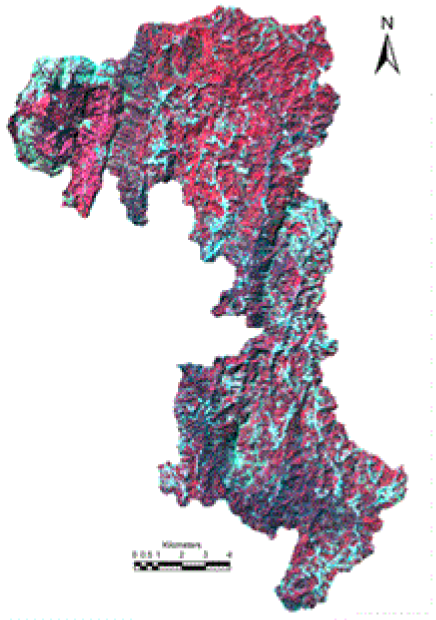

Figure 11: False Colour Composite of Study area.

Rainfall: Point data of daily rainfall from rain gauge stations for the period 1901-2010 [26,29,50] were used for the analysis. Some rain gauge stations had incomplete records with missing data for few months. The average monthly and annual rainfall data were used to derive rainfall map throughout the study area and was used to derive the gross yield (RG) in the basin (equation 1). Net yield (RN) was quantified (equation 2) as the difference between gross rainfall and interception (In).

$RG=A \times P$ ……. (1)

$RN=RG-In$ …… (2)

Where, RG: Gross rainfall yield volume; A: Area in Hectares; P: Precipitation in mm, RN: Net rainfall yield volume; and In: Interception volume

*Interception*During monsoons, portion of rainfall does not reach the surface of the earth; it remains on the canopy of trees, roof tops, etc. and gets evaporated. Field studies in Western Ghats show that, losses due to interception is about 15% to 30%, based on the canopy cover. Table 5 shows the interception loss across various rainy months and land uses.

Vegetation types	Period	Interception
Evergreen/semi evergreen forests	June-October	I=5.5+0.30 (P)
Moist deciduous forests	June-October	I=5.0+0.30 (P)
Plantations	June-October	I=5.0+0.20 (P)
Agricultural crops (paddy)	June	0
	July-August	I=1.8+0.10 (P)
	September	I=2.0+0.18 (P)
	October	0
Grasslands and scrubs	June-September	I=3.5+0.18 (P)
	October	I=2.5+0.10 (P)

Table 5: Interception loss.

Runoff: Portion of rainfall that flows in the streams after precipitation [2,8,10,11] are (i) surface runoff or direct runoff and (ii) sub surface runoff.

Surface runoff: Portion of water that directly enters into the streams during rainfall, which is estimated based on the empirical [9,10,11] relationships given in equation 3.

$Q=\Sigma(Ci \times PR \times Ai)/1000$……(3)

Where, Q: Runoff in cubic meters per month; C: Catchment/Runoff coefficient, depends on land uses as given in Table 6 [36]; PR: Net rainfall in mm; i: Land use type; Ai: Area of Landscape i as square meters.

Land Use	Catchment Coefficient
Urban	0.85
Agriculture	0.6
Open lands	0.7
Evergreen forest	0.15
Scrub/Grassland	0.6
Forest Planation	0.65
Agriculture Plantation	0.5
Deciduous Forest	0.15

Table 6: Catchment coefficients.

Infiltration: The portion of water enters the subsurface (vadoze and groundwater zones) during precipitation depending on land cover in the catchment. During field monitoring of streams in the forested catchment, overland flow is noticed in streams only after couple of days rainfall. This means that overland flow in the catchment with vegetation cover happens after the saturation of sub surfaces. The water stored in sub-surfaces will flow laterally towards streams and contributes to stream flow during non-monsoon periods, which are referred as pipe flow (during post monsoon) and base flow (during summer).

$Inf=RN-Q$…..…(4)

Ground water recharge: This is the portion of water that is percolated below the soil stratum (vadoze) after soil gets saturated. Recharge is considered the fraction of infiltrated water that recharges the aquifer after satisfying available water capacity and pipe flow. Krishna Rao equation, (equation 5) [19] was used to determine the ground water recharge.

$GWR=RC \times (PR-C) \times A$ …… (5)

Where, GWR: Ground water recharge; RC: Ground water recharge coefficient (Table 7); C: Rainfall Coefficient (Table 7); A: Area of the catchment. The recharge coefficient and the constant vary depending land uses with the annual rainfall.

Annual Rainfall	R_C	C
400 to 600 mm	0.2	400
600 to 1000 mm	0.25	400
>2000 mm	0.35	600

Table 7: Ground water recharge coefficients.

Sub surface flow (Pipe flow): Part of the infiltrated effective rainfall circulates more or less horizontally (lateral flow) in the superior soil layer and appears at the surface through stream channels is referred as subsurface flow. The presence of a relatively permeable shallow layer favors this flow. Subsurface flows in water bearing formations have a drainage capacity slower than superficial flows, but faster than groundwater flows. Pipe flow is considered to be the fraction of water that remains after infiltrated water satisfies the available water capacities under each soil. Pipe flow is estimated for all the basins as function of infiltration, ground water recharge and pipe flow coefficient, given by equation 6

PF=(Inf-GWR) × KP ……. (6)

Where, PF: Pipeflow; Inf: Infiltration volume; KP: Pipe flow coefficient [2]

Groundwater discharge: Groundwater discharge or base flow is estimated by multiplying the average specific yield of aquifer under each land use with the recharged water. Specific yield represents the water yielded from water bearing material. In other words, it is the ratio of the volume of water that the material, after being saturated, will yield by gravity to its own volume. Base flow appears after monsoon and receding of pipe-flow. This water generally sustains flow in the rivers during dry seasons. A portion of recharged water flows to the streams as ground water discharge which is dependent on the topography, geology and the land use conditions. Equation 7 defines Ground water discharge as product of specific yield and the portion of ground water recharged.

GWD=GWR × YS…..…(7)

Where, GWD: Ground water discharge; GWR: Ground water recharge; YS: Specific yield [2].

Estimation of water demand evapotranspiration

Evaporation is a process where in water is transferred as vapour to the atmosphere. Transpiration is the process by which water is released to the atmosphere from plants through leaves and other parts above ground. Evapotranspiration is the total water lost from different land use due to evaporation from soil, water and transpiration by plants. Some of the important factors that affect the rate of evapotranspiration are: (i) temperature, (ii) wind, (iii) light intensity, (iv) Sun light hours, (v) humidity, (vi) plant characteristics, (vii) land use type and (viii) soil moisture. If sufficient moisture is available to completely meet the needs of vegetation in the catchment, the resulting evapotranspiration is termed as potential evapotranspiration (PET). The real evapotranspiration occurring in specific situation is called as actual evapotranspiration (AET). These evapotranspiration rates from forests are more difficult to describe and estimate than for other vegetation types.

Potential evapotranspiration (PET) was determined using Hargreaves method (Hargreaves [2,36]) an empirical based radiation based equation, which is shown to perform well in humid climates. PET is estimated as mm using the Hargreaves equation is given by equation 8.

PET=0.0023 × (RA/λ) × √(Tmax-Tmin) × ((Tmax+Tmin)/2+17.8) …..…(8)

Where, RA: Extra-terrestrial radiation (MJ/m^2/day) [36]; Tmax: Maximum temperature [42]; Tmin: Minimum temperature [42]; λ: latent heat of vapourisation of water (2.501 MJ/kg)

Actual evapotranspiration is estimated as a product of Potential evapotranspiration (PET) and Evapotranspiration coefficient (KC) (Table 8), given in equation 9. The evapotranspiration coefficient is a function of land use varies with respect to different land use. Table 8 gives the evapotranspiration coefficients for different land use

AET=PET × KC……(9)

Land use	K_C
Built-up	0.15
Water	1.05
Open space	0.3
Evergreen forest	0.95
Scrub and grassland	0.8
Forest Plantation	0.85
Agriculture Plantation	0.8
Deciduous forest	0.85

Table 8: Evapotranspiration coefficient.

Note: the crop water requirement was estimated for different crops and different seasons based on land use, assumption is individual crop water requirement and different growth phases (need different quantum of water for their development inclusive of evaporation).

Domestic water demand: Understanding the population dynamics in a region is necessary to quantify and also to predict the domestic water demand. Population census for villages during 2001 and 2011 [24] were considered in order to compute the population of the basin level. Based on the rate of change of population (equation 10), the population for the year 2014 was predicted as given in equation 11.

r=(P2011/P2001-1)/n ……(10)

Where, P2001 and P2011 are population for the year 2001 and 2011 respectively; n is the number of decades which is equal to 1; r is the rate of change

P2014=P2011 × (1+n × r) ……(11)

Where, P2014 is the population for the year 2014; n is the number of decades which is equal to 0.3.

Domestic water demand is assessed as the function of water requirement per person per day, population and season. Water required per person includes water required for bathing, washing, drinking and other basic needs. Water requirements across various seasons are as depicted in Table 9.

Season	Water lpcd
Summer	150
Monsoon	125
Winter	135

Table 9: Seasonal water requirement.

Livestock water requirement: Household surveys were conducted with the structured questionnaires to understand the agricultural and horticulture cropping pattern and water needed for various crops in the catchment. Livestock population details were obtained from the district statistics office and water requirement for different animals were quantified based on the household interviews. Table 10 gives the water requirement for various animals.

	Water Requirement in lpcd (Liters per animal per day)							
Season\Animal	Cattle	Buffalo	Sheep	Goat	Pigs	Rabbits	Dogs	Poultry
Summer	100	105	20	22	30	2	10	0.35
Monsoon	70	75	15	15	20	1	6	0.25
Winter	85	90	18	20	25	1.5	8	0.3

Table 10: Livestock water requirement.

Crop water requirement: The crop water requirement for various crops was estimated considering their growth phase and details of the cropping pattern in the catchment (based on the data compiled from household surveys and publications such as the district at a glance, department of agriculture). Land use information was used in order to estimate the cropping area under various crops. Figure 12 provides the information of various crop water requirements based on their growth phase as cubic meter per hectare.

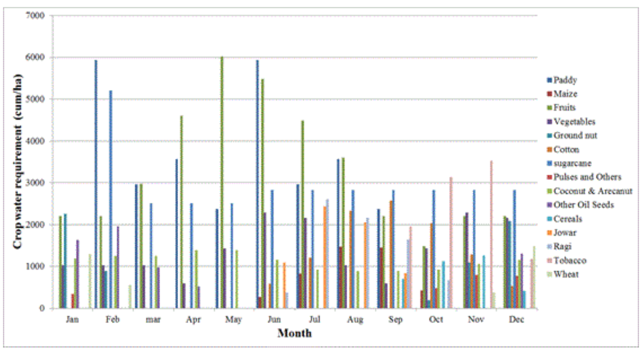

Figure 12: Crop water requirement (as cum per hectare per month).

Evaluating hydrological status: The hydrological status in the catchment is analysed for each month based on the water balance which take into account the water available to that of the demand. The water available in the catchment is function of water in the soil, run off (streams and river) and water available in the water bodies (Lentic water bodies such as lakes, etc.). Water demand in the catchment is estimated as the function of societal demand and terrestrial ecosystem (AET from forested landscape) crop water demand, domestic and livestock demand and the evapotranspiration. The catchment is considered hydrological sufficient, if the water available caters the water demand completely else the deficit catchment, if the water demand is more than the water available in the system.

Quantification of the environmental flow: Ecological investigations include the investigations of fish diversity across seasons. Habitat simulation method [51-56] was adopted to assess flows on basis of quantity and suitability of physical habitat available to target species under different flow regimes. In order to evaluate the natural flow regime [53,54], 18-24 months field monitoring of select streams in Sharavathi river basin and at Hongadahalla and Kadumanehalla (of Yettinaholé catchment) was carried out. This field data was compared with the long term flow measurements data at Hongadahalla and Kadumanehalla [45]. The natural flow that sustains native biota during lean season is accounted as the ecological or environmental flow [57-60] for the respective lotic system. In the current study, hydrologic assessment and investigations on the occurrence of native fish species (with diversity) helped in ascertaining the minimum flow required to sustain the native fish biota.

Results

Land use analysis

Land use analysis was carried out using remote sensing data of 2014, for Yettinaholé catchment (a tributary of Gundia River) and results are given in Figure 13 and Table 11. Major portion of the catchment is covered with evergreen forest (45.08%) followed by agriculture plantations (29.05%) and grass lands (24.06%). The valleys along the stream are dominated by agriculture lands and horticulture plantations, the hill tops dominated by grass lands, slopes covered with forest cover. The accuracy of the land use classification is 87% with kappa of 0.82. Temporal land use in the Gundia river catchment during 2000, 2006, 2010 and 2014 are depicted in Figure 14 and details are provided in Table 12. Results reveal that area under forests has reduced from 70.74% (in 2000) to 61.15% (in 2014).

Land use	Area (%)
Built up	0.07
Agriculture Plantation	29.25

Citation: Ramachandra TV, Vinay S, Bharath HA (2016) Environmental Flow Assessment in a Lotic Ecosystem of Central Western Ghats, India. Hydrol Current Res 7: 248. doi:10.4172/2157-7587.1000248

Evergreen	45.08
Forest Plantation	0.001
Water	0.002
Open land	0.91
Agriculture	0.62
Grassland	24.06

Table 11: Land use in Yettinaholé catchment.

The region receives annual rainfall ranging from 3000 mm to 4500 mm. Variability of rainfall was assessed based on 11 rain gauge stations in the catchment and is given in Figure 15.

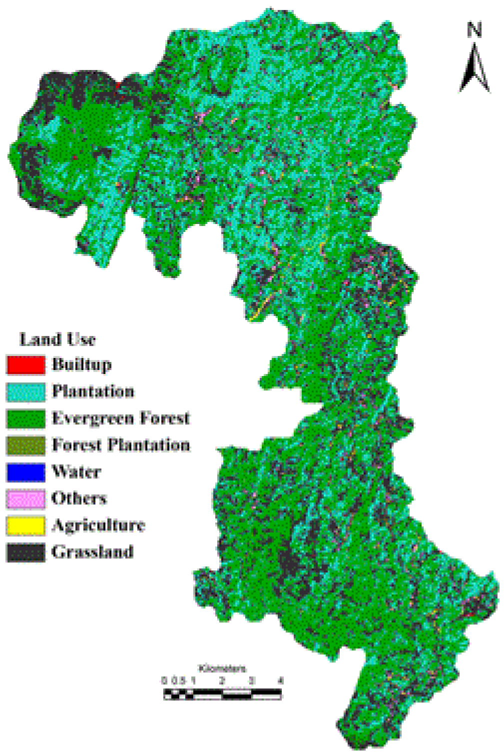

Figure 13: Land use in Yettinaholé catchment (eastern part of Gundya river basin).

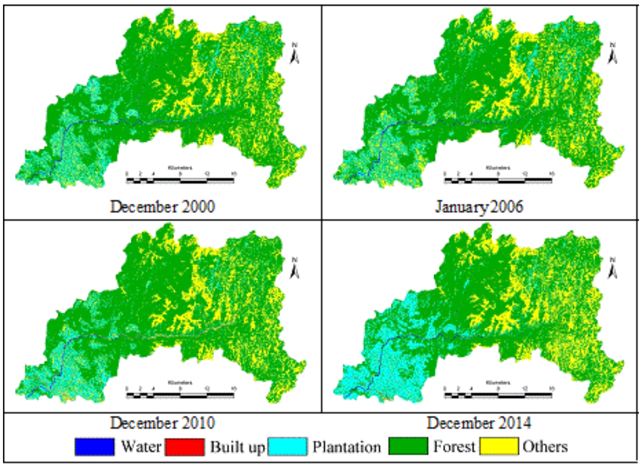

Figure 14: Land use dynamics-Gundia river basin.

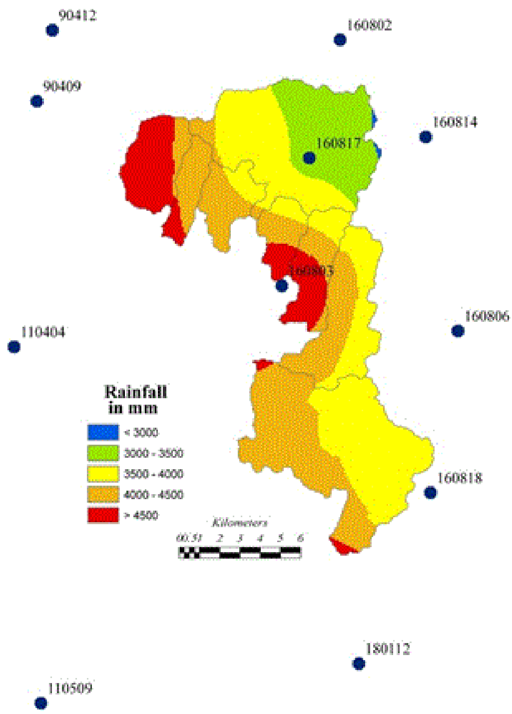

Figure 15: Spatial patterns of rainfall and rain gauge stations.

Land use	2000 December		2006 January		2010 December		2014 December	
	Area (sq.km)	% Area	Area (sq.km)	% Area	Area (sq.km)	% Area	Area (sq.km)	% Area
Water	4.05	0.63	3.61	0.56	2.96	0.46	3.11	0.49
Built up	0.44	0.07	0.17	0.03	2.41	0.38	2.72	0.43
Plantation	74.61	11.66	77.55	12.11	79.29	12.39	121.29	18.95

Forest	452.8	70.74	443.36	69.26	443.27	69.25	391.43	61.15
Others	108.22	16.91	115.44	18.03	112.18	17.53	121.56	18.99

Table 12: Land use dynamics - Gundia River basin.

Figure 16 provides the annual variability of hydrological parameters for understanding the hydrological regime. Gross rainfall, estimated as product of catchment area and rainfall. The gross rainfall varies from 33232 kilo.cum (in Kadumane holé 2 and Yettinaholé 2) and over 2000000 kilo.cum (in Yettinaholé and Hongada halla catchments). Portion of the water doesn't reach the earth surface, but is intercepted by the earth features namely the tree canopy, building tops, pavements etc., which gets evaporated. Runoff in the basin is estimated as a function of catchment characteristics along with rainfall. Yettinholé, catchment is covered predominantly by evergreen forests, has aided in recharging groundwater zone and sub surfaces. Infiltration of significant amount of precipitation to underlying layers, has reduced the overland flow and thus retarded the flash floods. The infiltration of water to sub-surface takes place during monsoon, and overland flow (surface runoff) happens during the monsoon (rainfall>50 mm per month) and quantity depends on the catchment characteristics namely land use/land cover in the catchment, soil porosity, texture, presence of organic matter (leave debris, decayed matter etc.). The portion of water percolates through the sub surfaces and thus recharges ground water resources. Water stored in vadoze zone (sub-surface) and groundwater zone moves laterally to streams with cessation of rain. Forests in the catchment have played a prominent role in maintaining stream flow, water holding capacity of soil, ground water, which also plays a pivotal role in catering the ecological and environmental demand of water. Sub basin wise yields are listed in Table 13; the surface runoff during the monsoon is estimated to be 9.55 TMC.

Sub basin	Average Annual Rainfall mm	Gross Rainfall TMC	Runoff yield as TMC
Yettina hole	3539.73	5.98	2.62
Yettina holé T2	4311.44	1.23	0.58
Yettina holé T1	4109.99	1.33	0.57
Kadumane holé 2	4364.85	1.2	0.53
Kadumane holé 1	4725.54	1.79	0.7
Hongadahalla	4000.77	6.7	2.68
Keri holé	4013.09	2.69	1.17
Yettina holé lower reach	4385.25	1.81	0.69
GROSS Yield (TMC)			9.55

Table 13: Catchment yield.

Evapotranspiration in the catchment depends on the land use, solar radiation, variations in temperature, precipitation, etc. Potential evapotranspiration was estimated using Hargreaves method. PET indicates the maximum possible water that can evaporate, PET varies between 160 mm/month (March) to 85 mm/month (monsoon season). Considering the various land use characteristics in the catchments, actual evapotranspiration was estimated in the catchments show variation of 40 mm/month (monsoon) to 120 mm/month (March).

Crop water demand was calculated in each catchment based on cropping pattern, area under each crop, and water required across the growth phases of the crops, which were compiled from various literatures (local, national and international) and discussion with the public regarding cropping practices and experiences. Table 9 and Figure 12, details season-wise crop water requirements and growth phases. The agricultural water demand of 2.6 TMC in the catchments is for horticultural and paddy cultivation. Livestock water demand given in Table 10 was estimated based on the livestock population (compiled from District at a glance of Hassan 2012-13).

Census data for the year 2001 and 2011 with the decadal rate of change in population was used compute the population for 2014 and water demand. Population for the year 2014 was estimated as 16156 persons. Catchment had a population of 17005 (in 2001), which decreased to 16345 (in 2011) at a decadal decline of 3.88%. The population density in the catchments varies from 33 persons per sq.km (in Keriholé) to about 150 persons per sq.km (Yettinaholé lower reach).

Ecological Flow Assessment: Flow measurements during the study period at two basins namely Hongadahalla and Kadumaneholé of Yettinaholé namely and based on the long term monitoring data [45] is given in Figures 16 and 17 respectively. This illustrates that flow during the lean season is about 10% of the annual flow, which is lower than the minimum flow requirement to sustain the ecosystem services in the water body.

Monthly monitoring of select streams in Sharavathi River basin over 24 months (covering all seasons) revealed the linkages of fish diversity with the duration of water flow in the respective stream. Table 14 lists the fish diversity across monitored streams. The current assessment confirm the requirement of 24 to 30% of annual flow during lean

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seasons to sustain the native fish diversity of endemic species [46,47]. Based on this, the ecological flow in Yettinaholé catchment (during the lean seasons) is 2.8 TMC.

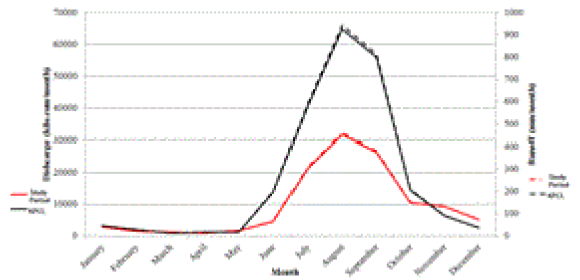

Figure 16: Hongadahalla.

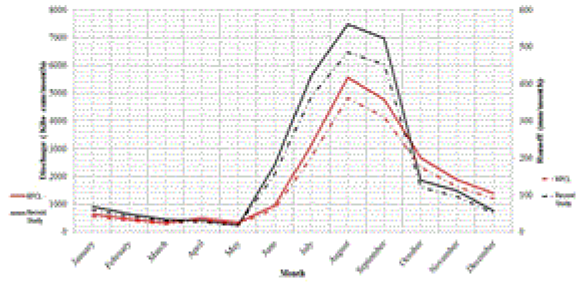

Figure 17: Kadumaneholé.

Fishes (Scientific Name)	Hill streams									
	Huruli River	Nagodi River	Birer River	Yenne River	Kouthi Stream	Sharavathi	Hilkunji	Sharmanavathi	Haridravathi	Nandihole
Amblyphyrngodon mola										
Aplocheilus lineatus	*	*	*	*	*	*	*	*		
Barilius canarensis			*		*					
Catla catla										
Chanda nama	*						*			
Channa marulius						*				
Cirhina fulungee						*		*		
Cirhina mrigala										
Cirrhinus reba								*		
Clarius byatracus										
Cyprinus carpio						*				
Danio aequipinnatus	*	*	*	*	*	*	*	*	*	*
Garra gotyla stenorynchus	*					*		*		*
Glossogobius giurus										
Heteropneustis fossilis										
Labeo fimbriatus										
Labeo rohita						*				
Lepidocephalichthys thermalis			*		*					
Mastacembalus arnatus						*				
Mystus cavesius	*									
Mystus keletius	*									
Mystus malabaricus	*									

Namacheilus rueppelli		*	*							
Ompok bimaculatus						*				
Ompok sp.										
Oreochromis mossambica										
Pseudambasis ranga	*									
Pseudeutropius atherenoides	*									
Puntius arulius					*					
Puntius dorsalis										
Puntius fasciatus	*	*	*	*	*					
Puntius filamentosis				*	*					
Puntius kolus										
Puntius narayani										
Puntius parrah										
Puntius ticto										
Rasbora daniconius	*	*	*	*	*	*	*		*	*
Salmostoma boopis						*	*		*	

Table 14: Fish diversity in select streams of Sharavathi River basin.

	Description	Quantity
1	Gross Area	179.68 sq.km
2	Average Annual Rainfall	3500 - 4500 mm
3	Water Yield in Yettinaholé catchment	9.55 TMC
4	Ground Water Recharge	0.49 TMC
5	Evapotranspiration	3.16 TMC
6	Irrigation Water Requirement	2.64 TMC
7	Domestic Water Requirement	0.03 TMC
8	Livestock Water Requirement	0.01 TMC
9	Total Water Demand (anthropogenic)	5.84 TMC
10	Ecological or environmental flow	2.8 TMC

Table 15: Hydrological assessment in Yettinaholé catchment.

The water demand and availability are listed in Table 15 and Figure 18 depicts the spatial variability of resources. Total water demand (5.84 TMC of water) across the catchments (accounting anthropogenic and evapo-transpiration of terrestrial ecosystems) was obtained as a function of evaporation, livestock, and domestic and agriculture demands. Availability of water in the catchment was assessed as a function of runoff during all seasons. The assessment showed that most streams in the forested catchment are perennial compared to steams in the catchment predominantly covered with monoculture plantations (6-9 months) or the streams in catchment dominated by open area or barren area (4 months). The available water in Yettinaholé catchment is sufficient to cater the existing water demand (social, ecological and environmental) throughout the year.

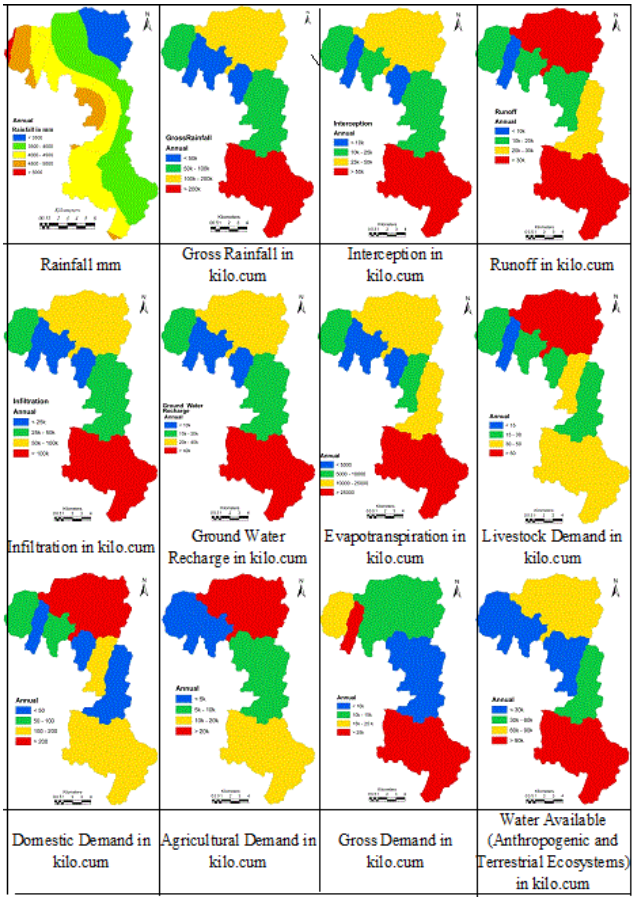

Figure 18: Hydrologic assessment in Yettinaholé catchment.

Conclusion

Yettinaholé River is currently catering to the anthropogenic and ecological water needs in the catchment. Higher discharge of water during monsoon has helped in the transport of nutrients, silt, etc., which has helped in sustaining the riparian's vegetation and aquatic life apart from meeting the anthropogenic demand (for horticulture, agriculture etc.). Many streams of Yettinaholé are perennial, which has helped in sustaining the rich and diverse aquatic life apart from sustaining horticultural, agricultural activities (3 crops per year) and fishery.

Hydrological yield computation shows the water yield in the catchment is about 9.5 TMC, About 5.84 TMC is required for domestic purposes including agriculture, horticulture and livestock rearing and the quantum of water required to sustain fish life in the streams is about 2 TMC. This highlights that water available in the catchment is sufficient to sustain the current ecological and anthropogenic (agricultural, horticultural) demand. Alterations in the catchment integrity (land cover) or water diversions would result in the variation in the natural flow regime affecting the biodiversity of riparian's and aquatic habitats and more importantly people's livelihood who are dependent on fisheries, etc. in the downstream. In this contyext, The federal government's plan to divert Yettinaholé River water to the dry arid regions in Karnataka is neither technically feasible, economically viable nor ecologically sound apart from depriving the anthropogenic demand in the Yettinaholé River catchment. The sustainable option to meet the water requirements in arid regions is through (i) decentralized water harvesting (through tanks, ponds, lakes, etc.), (ii) rejuvenation or restoration of existing lakes/ponds, (iii) reuse of treated waste water, (iv) recharging groundwater resources, (v) planting native species of plants in the catchment, (vi) implementation of soil and water conservation through micro-watershed approaches.

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Centenary Pond in Indian Institute of Science

Energy and Wetlands Research Group, Centre for Ecological Sciences,
Indian Institute of Science, Bangalore
Url: http://wgbis.ces.iisc.ernet.in/energy/

- Lakes , artificial or natural, hold water, helps in recharging sub surface waters, and help in maintaining balance.
- Habitat for diverse birds and other biota.
- Ground water table improvement
- Natural vegetation (Forests) helps in maintaining water in the lake and there by catering to the post monsoon water needs.

Objective : To depict the ability of water bodies in recharging ground water, creation of micro habitat by creating a well planned artificial lake.

IISc located at North western part of Bangalore (BBMP), with an area of 180 Ha.

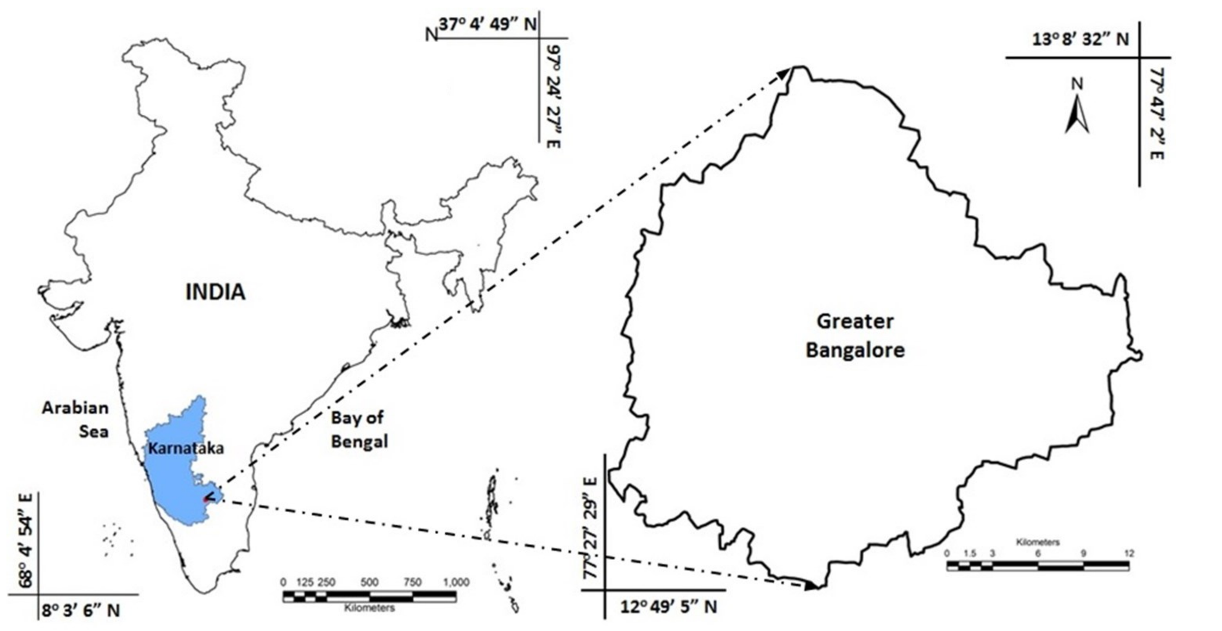
Lake was created in Jubilee Gardens of IISc on April 2008, named **Centenary Pond** (13° 1' 16.78'' N , 77° 34' 14.96'' E)

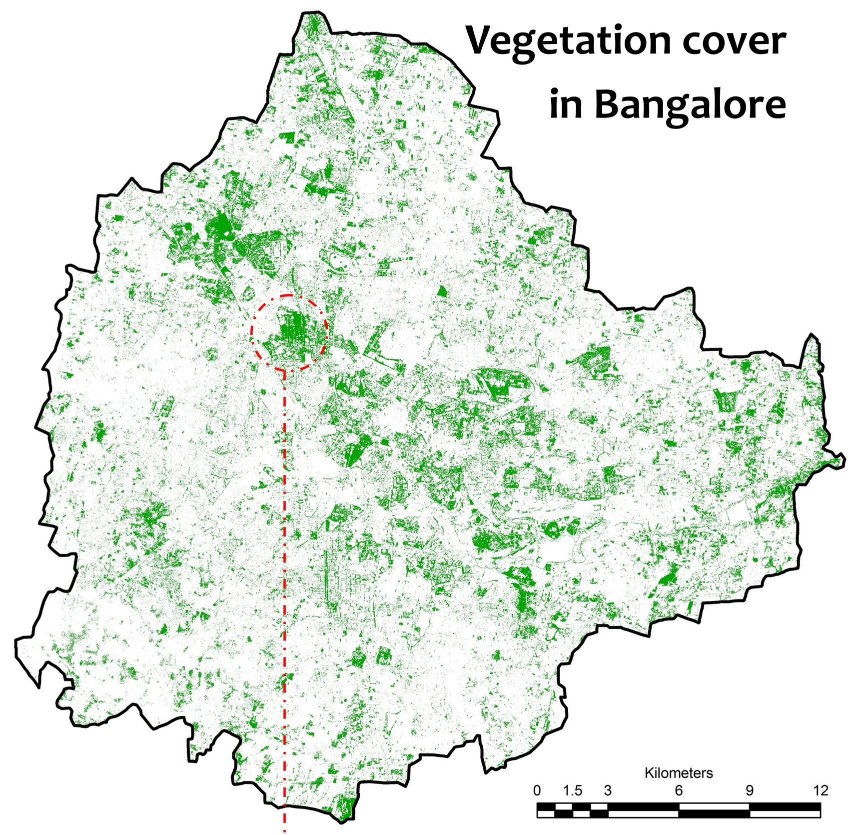
Area of Pond at FRL: 1.5 Ha, depth : 3m, water holding capacity : 48,000 cum

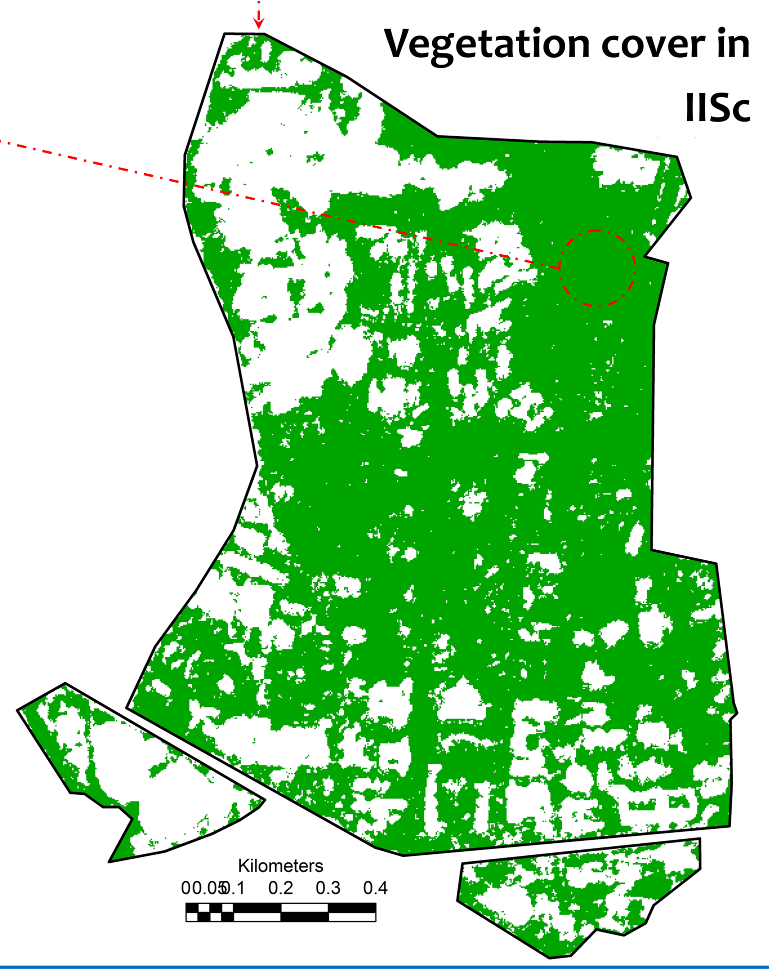
Created to : Harvest rain water, provide habitat for aquatic flora and fauna, recharge ground water table.

Vegetation in the campus : 107.85 Ha, with mini forest of 1.5 Ha

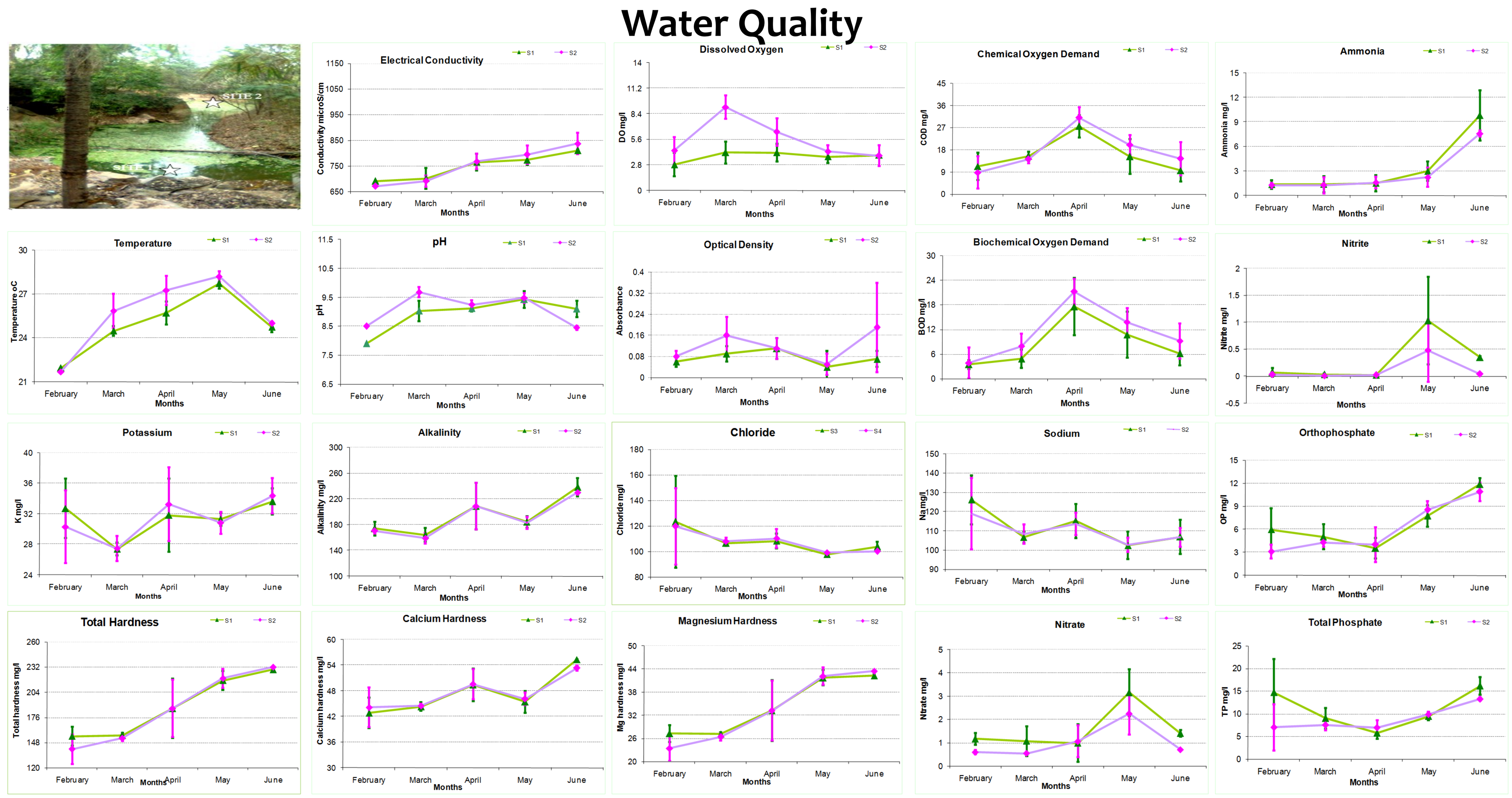
Homes several reptiles, mammals, birds, insects and many more faunal species



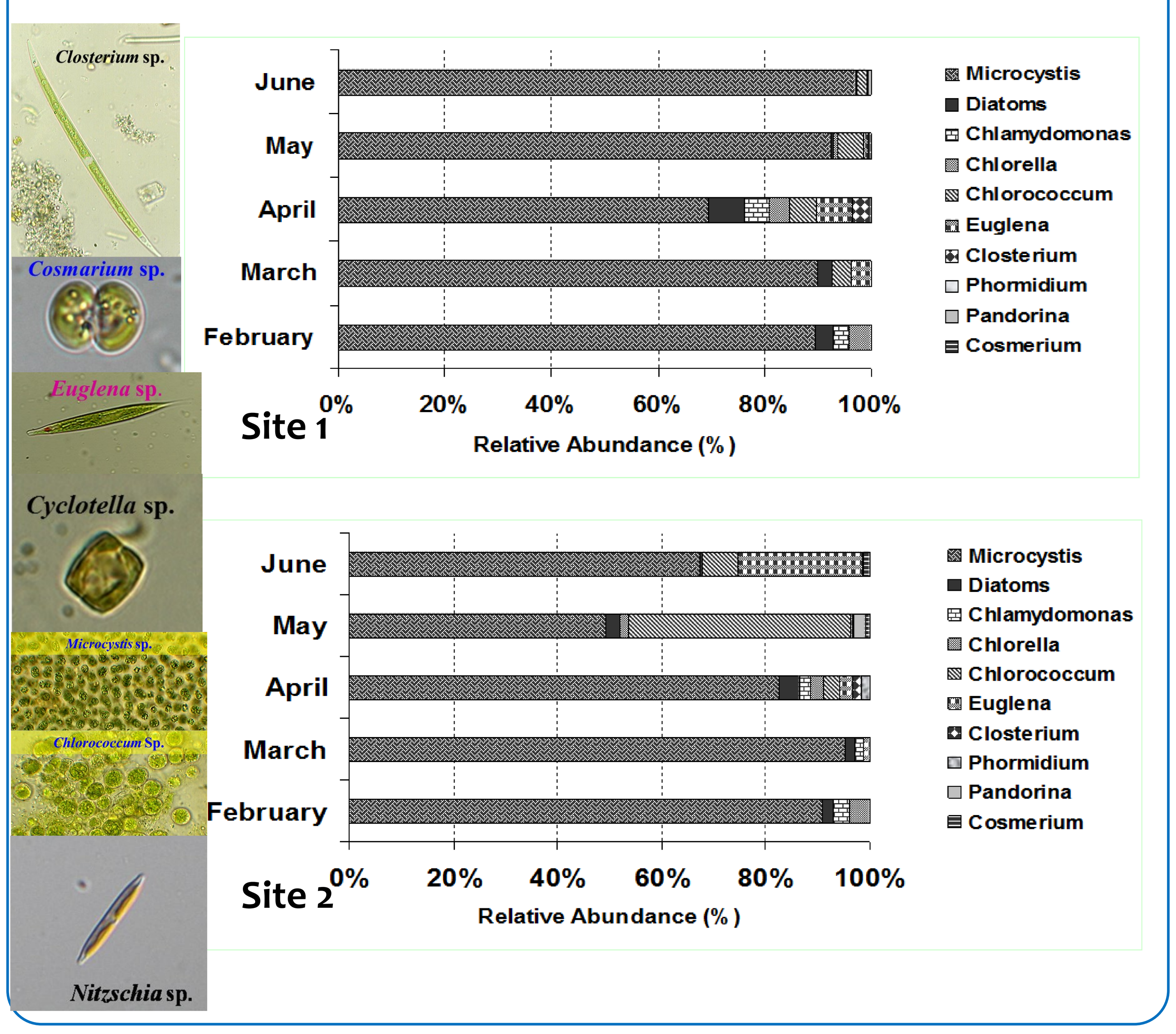




Water Quality



Relative abundance of microalgae community



1. Improved Ground water table in surrounding localities (from over 400 ft deep to about 100 ft deep)
2. The water quality has improved due to the nutrient uptake by algae and duck weed .
3. Area of IISc is equivalent to that of any ward of BBMP, and hence taken up in most of the wards in the urban pockets of India.

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Need For Rain Water Harvesting in the Context of Urbanization.

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SYNOPSIS

Sustainable management of natural resources has attained the attention of decision makers in the early 20th century consequent to the crisis faced by the society due to unplanned developmental activities. The anthropogenic activities have affected the quality and quantity of natural resources, which is evident from the disappearance of waterbodies, degraded catchments and increased organic pollutants in waterbodies, which necessitated optimal resource planning. Spatial and temporal tools such as Geographic Information System (GIS) are helpful in analyzing the spatial data. To meet the growing demand for water due to burgeoning population, planners attention is diverted towards alternatives such as rainwater harvesting, treatment of waste water, recycling, etc. Rainwater harvesting and artificial recharge of ground water augments the ground water storage and improves the condition of the other water resources in the vicinity. Rainwater harvesting forms one of the most cost-effective methods for improving the water resources for domestic water requirements.

This paper analyses the feasibility of a harvesting structure at Indian Institute of Science (IISc) campus using GIS. IISc covers an area of 180 ha and forms a part of Sankey lake catchment (located to south east of the Institute). The location and size of harvesting structure was identified with a detailed investigation of the land use pattern, hydrological analyses, catchment delineation, and identification of potential water demand areas. Ecological, economical, social and technical aspects were also considered. Harvesting structure with an area of 1.5 ha and a depth of about 3m can hold about 48,000 m^3 of water. This was found sufficient to meet the requirement of swimming pool, gardening and toilet usage in the campus. Topographical analyses with the help of Digital Elevation Model (DEM) created using Geomedia Professional 5.1 and Geomedia Grid, suggested suitable location of the harvesting structure at eastern side of the campus. About 1.5 ha land is available in this region to construct harvesting structure. Hydrological analyses were carried out taking into account various land uses (sub-catchment delineation) to assess the water yield in the eastern part of the campus. The cumulative annual yield of the catchment ranged from 0.4 million m^3 to 0.8 million m^3.

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1.0 INTRODUCTION

Urbanisation is a form of metropolitan growth that is a response to often bewildering sets of economic, social, and political forces and to the physical geography of an area. It is the increase in the population of cities in proportion to the region's rural population. The 20th century is witnessing "the rapid urbanisation of the world's population", as the global proportion of urban population rose dramatically from 13% (220 million) in 1900, to 29% (732 million) in 1950, to 49% (3.2 billion) in 2005 and is projected to rise to 60% (4.9 billion) by 2030 (World Urbanization Prospects, 2005). Urban ecosystems are the consequence of the intrinsic nature of humans as social beings to live together (Sudhira *et al.*, 2003; Ramachandra and Uttam Kumar, 2008, Ramachandra and Uttam Kumar, 2009; Ramachandra and Shwetmala, 2009). The process of urbanisation contributed by infrastructure initiatives, consequent population growth and migration results in the growth of villages into towns, towns into cities and cities into metros. Urbanisation and urban sprawl have posed serious challenges to the decision makers in the city planning and management process involving plethora of issues like infrastructure development, traffic congestion, and basic amenities (electricity, water, and sanitation), etc. (Kulkarni and Ramachandra, 2006). Apart from this, major implications of urbanisation are:

- **Heat island:** Surface and atmospheric temperatures are increased by anthropogenic heat discharge due to energy consumption, increased land surface coverage by artificial materials having high heat capacities and conductivities, and the associated decreases in vegetation and water pervious surfaces, which reduce surface temperature through evapotranspiration.

- **Loss of aquatic ecosystems:** Urbanisation has telling influences on the natural resources such as decline in number of water bodies and / or depleting groundwater table.

There has been a 632% increase in built up area from 1973 to 2009 leading to a sharp decline of 79% area in water bodies in Greater Bangalore mostly attributing to intense urbanisation process (Ramachandra and Uttam Kumar 2009). The rapid development of urban sprawl has many potentially detrimental effects including the loss of valuable agricultural and eco-sensitive (e.g. wetlands, forests) lands, enhanced energy consumption and greenhouse gas emissions from increasing private vehicle use (Ramachandra and Shwetmala, 2009). Vegetation has decreased by 32% from 1973 to 1992, by 38% from 1992 to 2002 and by 63% from 2002 to 2009. Disappearance of water bodies or sharp decline in the number of waterbodies in Bangalore is mainly due to intense urbanisation and urban sprawl. Many lakes (54%) were unauthorised encroached for illegal buildings. Field survey (during July-August 2007) shows that nearly 66% of lakes are sewage fed, 14% surrounded by slums and 72% showed loss of catchment area. Also, lake catchments were used as dumping yards for either municipal solid waste or building debris. The surrounding of these lakes have illegal constructions of buildings and most of the times, slum dwellers occupy the adjoining areas. At many sites, water is used for washing and household activities and even fishing was observed at one of these sites. Multi-storied buildings have come up on some lake beds that have totally intervene the natural catchment flow leading to sharp decline and deteriorating quality of waterbodies. This is correlated with the increase in built up area from the concentrated growth model focusing on Bangalore, adopted by the state machinery, affecting severely open spaces and in particular waterbodies. Some of the lakes have been restored by the city corporation and the concerned authorities in recent times.

Unplanned urbanisation has drastically altered the drainage characteristics of natural catchments, or drainage areas, by increasing the volume and rate of surface runoff. Drainage systems are unable to cope with the increased volume of water and are often encountered with the blockage due to indiscriminate disposal of solid wastes. Encroachment of wetlands, floodplains, etc. obstructs floodways causing loss of natural flood storage. Damages from urban flooding could be categorized as: direct damage – typically material damage caused by water or flowing water, and indirect damage – e.g. traffic disruptions, administrative and labour costs, production losses, spreading of diseases, etc.

Over exploitation of surface water sources like wells for drinking water and industrial use has also resulted in depleted water levels and drying up of bore wells or sea water intrusions (in coastal area) due to the imbalance of inflow and outflow for sub-surface water. The urbanization has also reduced original permeable ground surface. Pavements, roads and construction of storm water drains to drain the rain water as quickly as possible to natural stream, river or sea to avoid flooding of grounds and disruption in traffic. These surfaces and quick run off gives no scope for percolation of rain water to replenish the sub-surface aquifer causing the dropping of water levels or drying up of wells. In addition to this, land use and land cover changes (involving the large-scale conversion of natural ecosystems) have contributed to the regional and global climate changes, resulting in irregular, reduced, erratic and uncertain rainfalls. Dwindling of water resources coupled with the increased water demand has necessitated the viable alternatives to cater the water requirement. This highlights the need to conserve and augment the renewable natural water resources as last chance for survival, realizing that natural resources are not unlimited if they are exploited beyond certain limit. Conservation and sustainable management practices helps in the restoration of the natural balance. This requires the adoption of basic ecological principles in the management of natural resources to ensure the sustainability. In this context, rainwater harvesting is seen as a viable alternative to augment water resources.

1.1 Natural resources management:

Water is a renewable natural resource and plays a pivotal role in the region's development. However, unplanned anthropogenic activities have lead to the scarcity of resources, which has affected the economic, productive, infrastructural and social sectors. Scarcity of water is becoming a limiting factor for sustainable development in many parts of the world. Due to these, infiltration of rainwater into the sub-soil has decreased drastically and recharging of groundwater has diminished. The solution to achieve sustainable development lies in the efficient management of water and other natural resources. Rainwater is the main source of water and annually 300 to 800 mm of seasonal rainfall is lost as surface runoff or deep drainage. Water harvesting can also be achieved by following the watershed-based approaches in ecosystem management using pre-treated catchment and micro-catchment areas to increase the efficiency of runoff and maximize the amount of collected rainfall. Better management of water resources is achieved through water conservation, inter-sectoral water reallocations, water costing, and by using water efficiently. In water stress region, rainfall is collected from areas specifically treated to increase precipitation runoff and stored in tanks or ponds for human and animal consumption and for supplemental irrigation.

1.2 Planning:

If collection and storage are designed carefully, it is possible to cater water demand even in areas with rainfall as little as 400 mm / year. Analysis shows that between 80 to 85 % of all measurable rain can be collected and stored from the catchment area, which includes light drizzle and dew condensation. The run-off from a catchment area is computed (Raghunath,1995) by considering the spatial extent of a catchment (A), catchment coefficient (C, that depends on the land use pattern in the catchment) and rainfall intensity (I) and is given by $Q = C * I * A$ [Where, Q = discharge (m^3), C = co-efficient of run-off, I = total rainfall / annum (m) and A = catchment area (m^2)].

The co-efficient of run-off depends upon the land use pattern in the region. The catchment coefficient for rocky and impermeable: 0.8-1.0; slightly permeable, bare: 0.6-0.8; cultivated or covered with vegetation: 0.4-0.6; cultivated absorbent soil: 0.3-0.4; sandy soil: 0.2-0.3; heavy forest: 0.1-0.2.

The co-efficient of run-off also depends on the shape, size, soil conditions, temperature, and geological conditions of the area of the catchment. However, on the basis of average annual rainfall and land use in the area, the co-efficient can be assumed, which are listed in Table 1.

1.3 Spatial and Temporal Analyses:

Sustainable management of natural resources depends on optimal planning based on spatial and temporal data. In this regard, GIS aids as a dynamic and versatile technology capable of providing information for efficient planning and implementation. The unique feature of GIS is its ability as decision support system and provides answers to the queries through rational and systematic analysis of the situation. This aids planners to take quick decision.

For example, in order to understand the topographic undulation a DEM is generated with the help of GIS. It consists of terrain elevations for ground positions at regularly spaced horizontal intervals. DEM data are arrays of regularly spaced elevation values referenced horizontally to a geographic coordinate system. The grid cells are spaced at regular intervals along south to north profiles that are ordered from west to east. A DEM is a set of points defined in a three–dimensional Cartesian space (x, y, and z) that approximates a real surface. X and Y-axis may be expressed as geographic co-ordinates (i.e. longitude and latitude), whereas Z-axis usually represents the altitude above sea level. The low elevation areas are identified by creating the DEM with the contour data, which helps the decision makers in selecting the sites for setting the rain water harvesting structure.

The repetitive synoptic coverage provided by the space borne sensors (which operates on various bands of electro magnetic spectrum) has been widely used for mapping and monitoring areal extent of natural resources including surface water bodies / reservoirs. This is useful for reliable estimation of storage capacity of the reservoirs and its changes over the years. Ground water surveys through satellite remote sensing have been found to narrow down considerably the areas for detailed ground water exploration.

Management tasks of conserving available resources to meet growing demands and preserving water quality, compatible with socio-economic and environmental constraints have become exceedingly complex. In this context, remote sensing provides spatial data at regular interval and aids as a powerful tool for inventorying and monitoring water resources. Spatial analysis is done to get an idea about the terrain, to identify water logging area (seasonal and annual), and to identify sites for rainwater harvesting.

2.0 OBJECTIVES

Design of structures for optimal harvesting of rainwater using GIS includes

- Creation of the topographical elevation model.
- Identification of suitable sites for locating water harvesting structures using DEM.
- Land use analyses in the catchment.
- Computation of water yield.
- Study of geological and soil characteristics for civil design of the structure.
- Optimal design of rainwater harvesting structure considering the demand.

3.0 STUDY AREA

Indian Institute of Science (IISc) campus has been considered for the present study. The campus limits are enclosed within 13°00'38"N to 13°01'15"N latitude and 77°33'34"E to 77°34'26"E longitude. The area falls in the 57G/12 of SOI topo-sheet of scale 1:50000, 57G of scale 1:250,000. IISc is located in northern part of Bangalore city and Figure 1 gives the map of IISc campus with important landmarks. It is endowed with lush green vegetation and has a green canopy of trees covering the buildings in the campus.

The campus, consisting of five bounds, covers an area of 180 ha. The main campus covers 158 ha. The altitude of campus varies from 914m (from Mean Sea Level) to 942 m. The natural terrain of the campus is rolling and provides good natural drainage. The campus slopes towards three sides (north, east and west) from a central ridge along the middle and along the main road of the campus (Gulmohar Marg). Historical precipitation data of 54 years reveal that, the major portion of rainfall being May-June and thunderstorms during September-October. Bangalore receives mean annual rainfall of 860 mm (Radhakrishnan *et al.*, 1996). Sankey Lake located to the Southeast of the campus. A large drain running all along the eastern side of the campus forms the main feeder of the Sankey Lake.

4.0 METHODOLOGY

4.1 Development of database (spatial and attribute data) for GIS

The Survey of India (SOI) toposheets of scale 1:1000 of IISc campus in 10 sheets and GIS software Geomedia Professional 5.1 and Geomedia Grid were used to build the vector layers of

IISc boundary, boundary with landmarks, buildings, roads, surrounding lakes of IISc, IISc zones based on utilities, tree distribution, canopy cover in IISc based on NDVI ranges, drainage and contours.

A vector layer of vegetation showing all the trees (species wise) in the IISc was prepared through an extensive field survey carried out simultaneously. Contour maps (generated using Geomedia Professional 5.1 and Geomedia Grid) are used to generate slope maps of the area and DEM.

The SOI toposheets (scale 1:1000) were scanned and georegistered in geomedia professional. For georegistration a feature class definition of point feature was made and the original corner points from the topsheets were inserted for that point feature class. Then the scanned toposheet was brought to the geoworkspace working window with the help of insert interactive images. The image is selected through the select tool and source control point and target control points are inserted through the image registration dialog. For each feature class, projection system is defined and the datum and projection is set as per the geographical location of the region and through digitization of the raster image, individual features (like roads, contours etc.) are transformed to vector format.

Different feature class (layers) of IISc was created. This includes boundary, boundary with landmarks, buildings, surrounding lakes, zones based on utilities, tree distribution, canopy cover and contour layer (1m interval) by digitizing toposheets SOI (scale 1:1000).

4.2 DEM generation in GEOMEDIA grid

The contour feature (layer) of one m interval is brought to the geoworkspace working window and new study area is defined and cell resolution and output unit is set for the new study area. The contour features are selected from the legend and are rasterized. Through the edit window the non-void cells values are combined and the values are noted and one third of the noted value is calculated for random sampling. The output unit is set from the information dialog, same as that of the output unit of study area defined. Interpolation of the random sample result layer is done and the interpolated layer is smoothed. The depression (in DEM) is filled for the smoothed layer. The filled depression layer's name with color assignment to the layer was done through the edit window (by selecting the first and last cell in the edit window and right clicking on the selected cells to assign color's through color sequence dialog) of filled depression layer. For DEM, the shaded relief model is made with the filled depression layer and is viewed in the map window.

4.3 Field Investigation

A detailed field survey was undertaken to map trees (with diameter >10 cm) in the campus. Figure: 2 shows tree distribution in IISc campus. The field investigation gave an idea of the terrain, drainage pattern, vegetation cover and other constraints. Apart from this, a detailed field survey was under taken to map trees in various sub catchments. The drainage network of the campus was also studied to find out the possible problems of channeling the rainwater. The slope of the drains was also noted to delineate the catchment for the Pond. The local problems like blockage, clogging of the drains were also noted, so that remedial actions could be taken.

4.3.1 Storm-water pond

Economic and ecological considerations highly favor the creation of a water body inside the campus and divert the storm water generated in the campus to the pond. The water stored in the pond may be used for various purposes such as gardening and for meeting the non-drinking water needs of the adjacent buildings. A small filtration plant near the pond would help in treating the stored water usable for various purposes. A garden may be developed around the pond to enhance the aesthetic appeal. Creation of the water body, apart from providing usable water, is also advantageous from ecological considerations by providing a water source for the number of bird species (about 110 species) that the campus is proud to be a habitat.

The need to conserve water assumes more importance than ever before in the present scenario of water table depletion due to increased demand and over exploitation of groundwater resources. Surface water harvesting has multiple advantages, viz., recharge of ground water and efficient use of rainwater, which otherwise gets wasted or contaminated. This study through spatial and temporal data highlights the parameters to be considered for designing harvesting pond at an appropriate suitable location in the campus. The harvesting pond is designed with a detailed investigation of land use pattern, hydrological analyses, catchment delineation and identification of potential problem areas. The optimal design was arrived at taking into account ecological, economical, social and technical aspects.

4.4 Data analyses

Data analyses involved:

Calculations of the area of sub-catchments and land use analysis,
Computation of water yield in respective sub-catchments,
Suitable location of harvesting structures,
Optimal capacity of the pond.

The sub-catchments were delineated from the main catchment area and coefficients of runoff were given to each according to their catchment characteristics. The daily precipitation data at Bangalore city observatory from 1990 to 1997 were used to arrive at a water yield of the pond. Daily yield was calculated using the rational formula, which was computed for the catchment for all these years. Daily yield was cumulated to obtain the monthly and yearly yields.

Topographical analyses with the help of DEM suggest suitable location of the harvesting structure in the eastern part of the campus, which is currently a marshy region. About 1.5 hectare land is available in this region to construct harvesting structure.

During the early 1960's, there were many lakes around the campus that acted as water storage structures and aided in groundwater recharge mechanism. Anthropogenic stresses have led to conversion of lakes to residential, commercial layouts and public utilities. Recent study shows that about 35 % lakes have disappeared during the last twenty years (Deepa, et al. 1998).

Aswathnarayana-kere and Nagashettihalli-kere in the vicinity of IISc are now non-existent, and have been converted into residential layouts. Figure 3 shows the IISc campus bounded by the existing lakes. Consequently, during peak rainfall season, water from the catchment gets into the low-lying areas adjacent to the IISc campus (like ISRO Head quarters, Vigyanapura, etc.).

The three-dimensional elevation image generated using Geomedia Grid was used to identify suitable location for this rainwater-harvesting pond. Figure 4 shows the DEM of the IISc campus. With an identification of lowest positions in a region, the possibility of channeling water was explored considering the following aspects.

Social	:	Acceptance of pond and usage of its water by people in the vicinity. Proper managerial solution to avoid breeding of mosquitoes.
Technical	:	Remedial measures to prevent water seepage into the soil taking into account the stability aspects of structures in the vicinity.
Ecological	:	Environmental impact assessment to ensure minimum damage to the ecosystem from biodiversity point of view.
Economical	:	To ensure cost effective structure.

All possible locations were identified in the campus. The best option was selected considering above criteria and based on the simplicity of construction and channeling of the storm water. The pond was located at a point where the storm water drained can be channeled without much alterations of the existing drainage network.

After identification of suitable location for constructing harvesting structures (ponds), region was explored to find out the extent of land available. Location and area were decided based on ecologically sound strategies. From the land use map, Figure 5 gives the land use map of IISc campus based on utility (vector layer) of the spatial coverage of possible harvesting structure (pond / reservoir) was prepared. The area available ranges from 1 to 1.5 ha. One and half hectare spatial coverage entails removal of about 15 trees belonging to *Acacia nilotica* species. Considering these two areas and for different depths, capacity of the pond was computed. Volumes were compared with the water yield of the catchment of the campus considering the continuity equation i.e.

Storage volume = Inflow – Outflow - Losses (evaporation, seepage, etc.)

The losses considered were the evaporation from the catchment using the monthly mean of daily evaporation data for Bangalore (Muthreja, 1995). The demand for the swimming pool, gardening was ascertained from the volume of the swimming pool and the volume of the storage tank for gardening respectively.

The average rainfall of Bangalore was computed taking 55 years (from 1940 to 1997- 1948, 1967 were not available) of daily rainfall data from Bangalore city observatory.

Harvesting structure in an available area of 1.5 ha and a depth of about 3 m can hold about 22000 m^3 of rainwater. This is sufficient to meet the requirement of swimming pool, gardening and toilet usage in the campus. The campus swimming pool approximately requires 1000 m^3 of water per refilling. The pool faces scarcity of water during the lean season (i.e. during month of January, February and March). Apart from this, storage structures helps in recharging of the groundwater sources.

The maximum depth available at the proposed site is about 1.5 m. It is desirable to increase this to about 3m, so that the storage may be increased. All round excavation may be taken up to achieve a maximum depth of about 3 m, and to give aesthetic appearance.

Inlet to the pond: The existing main drain that runs in the eastern parts of the campus collects a major portion of the storm water. The lowest point on this drain occurs opposite to the proposed pond location, which could be easily connected to the pond.

Outlet from the pond: An outlet drain of size 1.8 m width and 1.2 m height must be provided at a slope of 1 in 1000, and joined to the existing drain leading to the municipal drain along the eastern part. The invert level of this outlet drain must be the same as that of the inlet drain.

Maintenance of water quality: Adequate care and attention must be focussed on maintenance of clear water in the pond, so that it does not become a source for unhygienic and unpleasant surrounding. Under no circumstances, sewage water and other waste water must be permitted inside the pond. For prevention of mosquito breeding, periodic treatment with lime and/or biological control is required.

5.0 RESULTS, DISCUSSION AND SUGGESTIONS

The base layers of the IISc campus for the analysis were generated using Geomedia Professional 5.1. From the scanned maps of SOI 1:1000 sheets. IISc campus covers an area of 180 ha, of this main campus occupies about 158 ha. Gymkhana bounds is about 10 ha, followed by ASTRA, Post office bound (7.5 ha), KV bounds (3.86 ha) and Staff quarters bounds (0.32 ha)

The two main roads, Gulmohar and Tala Marg run parallel along the middle of the campus as shown in Figure 6. The buildings were classified based on usage as administrative, academic, residential, library and information services, dining facilities, recreation and amenities, sister institutions (NIAS, JNCASR, INSDOC, TIFR), utilities and others (which included unidentified and unused buildings). The Faculty hall or the main building of the campus and other administrative buildings are shown in red color.

The elevation contours (topographic elevation) of the campus was generated by digitizing line features from the scanned maps. The generated contours indicate that, elevation in campus varies from 914 m (along the periphery of the Jubilee garden extension) to 942 m (near C.N.R. Rao circle closer to IISc main gate). The campus slopes towards three sides from the ridge that falls along the Gulmohar Marg (road from C.N.R. Rao circle to TIFR).

The contour map of the campus shows that the campus has a good natural drainage. Figure 7 shows the drainage network of IISc campus overlaid on contours. Hence, the problems of water stagnation in the campus are not grave except for some local problems. In addition, due to the gradient that is available, runoff drains off quickly. The natural drainage drains towards the either side of the main road. The drains are classified on their shape. The drains sloping towards the eastern side joins the large drain flowing towards the Sankey Lake.

The new buildings that were not available in the scanned maps were added using Global Positioning System and the shapes of these buildings are guesstimate. The percentage plinth area of the buildings, tree density, species diversity indices were calculated for each zone and this analysis also helped in arriving at the runoff coefficients.

The location of harvesting structure / storage pond was based on the topographical elevations, existing drainage network, area available and land use / land cover. Campus slopes toward either side from the middle ridge, lending to mainly two drainage directions. The eastern side of the campus has a greater gradient / slope than the western side. The eastern side has positions of low altitude compared to other areas of campus. Moreover, the major portion of the drainage flows to the eastern side. In addition, the large drain flowed along the eastern side (main feeder to Sankey Lake) to which all the eastbound drains lead.

Two areas identified for locating harvesting structures / pond are along the periphery of Jubilee garden having an altitude of 914 to 915 m and at the marshy area on the eastern side having an altitude from 917 to 920 m.

Among these locations, area having an altitude around 914 m was unsuitable because of retrograde natural drainage, lesser area available and difficulty of water being channeled to that area. The campus was also explored for other possible locations. The western side of the campus lacked any suitable site where possible structures could be located.

Moreover, marshy area collects rainwater during monsoon season and wetness is present throughout the year. In view of these, location is selected for the proposed harvesting structure which can cater the water requirement of swimming pool and garden and also be a good recreational spot. The proposed rain water harvesting site is indicated in Figure 8.

The marshy area was selected because it is located in low lying area naturally holding water and this endeavour proposes to modify the existing condition of the area to hold water. The area where the structure is being located has minimum number of trees.

The DEM was generated from the vector contour map using the linear surface interpolation and converted to a raster image. This image was used to visually identify the possible locations for the structure. This confirms the location of proposed harvesting structure in the marshy area (eastern side of the campus). The accuracy of DEM generated from the vector map depends on the no of rows and column selected during the conversion. The DEM was used only for visualisation of the terrain as against the extraction of drainage characteristics.

The spatial extent available for pond would be 1 to 1.5 ha depending on the inclusion or exclusion of the vegetated area around the pond. A depth of 1.5 m can be achieved without any excavation of the present pond bed. The volume of the pond that can be constructed depends on the area available. Table 2 shows the volume of pond for 1 and 1.5 ha for different depths (ranging from 1 m to 5 m).

In order to arrive at the optimal capacity of the proposed harvesting structure / storage pond water demand in the vicinity (such as swimming pool, garden etc.) was explored. The water supply for the Institute swimming pool comes from the Bangalore water supply in addition to well water. There is a shortage of water supply during lean season (December to March). Swimming pool being recycled twice a week its monthly requirement comes to around 4000 m^3. Assuming a pond capacity of 10000 m^3 (if spatial coverage of pond is 1 hectare and depth 1 m), this would be sufficient for two months after the evaporation losses.

The gardening requirement for the Institute is about 6000 m^3 / month. For 10000 m^3 of capacity, this would only be sufficient for 45 days. If the requirement for the swimming pool and the gardening is analysed this would be hardly sufficient for one month.

Instead, a capacity of 15000 m^3 achieved through 1.5 hectare area and a depth of 1 m, can support the swimming pool requirements for three months after evaporation losses. For gardening purposes, it would be sufficient for two months. Both requirements combined would suffice for 40 days. A capacity of 30000 m^3 (if spatial coverage of pond is 1.5 hectare and depth of 2 m), would be adequate to cater both swimming pool and garden annual water requirements. Figure 9 shows the canopy cover of IISc campus based on NDVI ranges.

The possibility of pond water catering to toilet usage in the campus was also analysed. This calculated on the assumption that 50 people each in 50 departments use 20 litres / person / day. This works out to 1500 m^3/month, which is to be supplied throughout the year. The swimming pool, garden and toilet water requirement on campus amounts to 48000 $m^{3.}$ Since there is sufficient yield in this catchment, to harvest this quantity, in an available area of 1.5 ha the depth has to be 3.2 m.

The rainwater harvesting structure could be built as earthen structure like a percolation pond but with adequate inflow and out flow structures. This also results in a cost-effective structure. A small filtration plant near the pond would help in treating the stored water usable for various purposes. A garden may be developed around the pond to enhance the aesthetic appeal. Suitable measures could be undertaken subsequently for maintaining the pond in a good condition, so that mosquito breeding (through biological control-successfully managed elsewhere) and other undesirable conditions may be avoided.

As a rainfall harvesting method to conserve water, another efficient method is to install a roof water harvesting system for each building, which is more cost effective and more efficient in solving the water scarcity in the lean seasons. This water can be used for laboratory usage, toilet usage and for other purposes if some simple treatment is given. This treatment can be simple chlorinating to be bacteriologically safe. Also filtering the water through a sand filter would be appropriate.

6.0 CONCLUSIONS

A comprehensive spatial database has been developed as a tool in aiding decision making for future development. The GIS is used for design of pond to harvest rain water optimally, considering economic and ecological considerations. The surface water stored in the pond may be used for suitable purposes such as gardening and for meeting the non-drinking water needs of the adjacent buildings.

The low-lying area adjacent on the eastern side is most suitable for the water body. Approximately 1.5 ha of low-lying area is available at this site. About 20,000 m^3 of water may be stored in this pond. This site also provides an easy opportunity for diverting a major portion of the storm water generated inside the campus, to the pond. The excess water from the pond may be diverted into the drain going out of the campus through the adjacent CPRI campus.

An outlet drain of size 1.8 m width and 1.2 m height must be provided at a slope of 1 in 1000, and joined to the existing drain on the eastern side leading to the municipal drain along the New BEL road. The invert level of this outlet drain must be the same as that of the inlet drain. It is emphasized that this drain must be of the minimum size mentioned above, and the existing drain that passes through the CPRI campus, to which the outlet drain from the pond is joined must be enlarged to the same cross section (1.8 m x 1.5 m). Adequate care and attention must be focussed on maintenance of clear water in the pond, so that it does not become a source for unhygienic and unpleasant surrounding. Under no circumstances, sewage water and other waste water must be permitted inside the pond.

It is emphasized that a good maintenance of the drainage system is as important as its design and construction. It is necessary that a periodic cleaning of drains, inlets, outlets, culverts etc., is taken up, to remove the muck, weed, solid wastes and other obstacles that may have been deposited, at least once before every monsoon. Like any other service facility, the system will work well when it is needed the most only if it is maintained well even when it is not needed.

ACKNOWLEDGEMENT

I thank the Ministry of Environment and Forest, Government of India and IISc for financial assistance and infrastructural support. I acknowledge M/S Intergraph and Rolta India Ltd. for providing GIS softwares Geomedia Professional 5.1 and Geomedia Grid, which helped in creating vector layer and DEM. We thank Mr. Praveen Kumar Gautam (M/S Intergraph Rolta India Ltd.) for the software support.

ABBREVIATIONS

BEL- Bharath electronics limited
CPRI-Central power research institute
INSDOC-Indian national scientific documentation centre
ISRO-Indian space research organization
JNCASR-Jawaharlal Nehru centre for advanced scientific research
KV-Kendriya vidyalaya
NDVI- Noramalized difference vegetation index
NIAS- National institute of advanced studies
TIFR- Tata institute for fundamental research

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Table 1: Catchment coefficient for various land uses.

Catchment Type with rainfall and runoff	Run off co-efficient
Dry tracts with annual rainfall 350 to 750 mm, run off 15 to 20 %	0.15 to 0.2
Intermediate Zones rain 750 to 1500 mm, run off 20 to 30 %	0.2 to 0.3
Higher Zone with rainfall above 1500 mm, run off 30 to 55 %	0.3 to 0.55
Roof and paved areas, run off 80 to 90 %	0.8 to 0.9

Table 2: Volume computation for various depths

Area 1 ha		Area 1.5 ha	
Capacity (m^3)	Depth (m)	Capacity (m^3)	Depth (m)
5000	0.5	7500	0.5
10000	1	15000	1
15000	1.5	22500	1.5
20000	2	30000	2
25000	2.5	37500	2.5
30000	3	45000	3
35000	3.5	52500	3.5
40000	4	60000	4

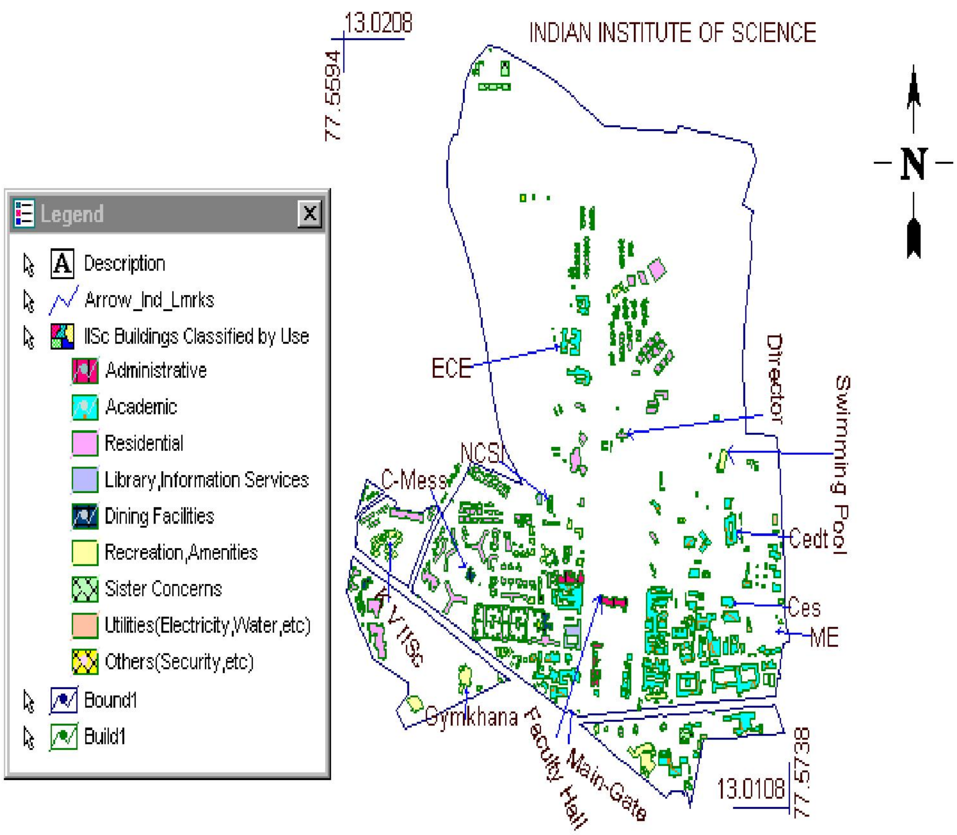

Figure 1: Map of IISc campus with important landmarks.

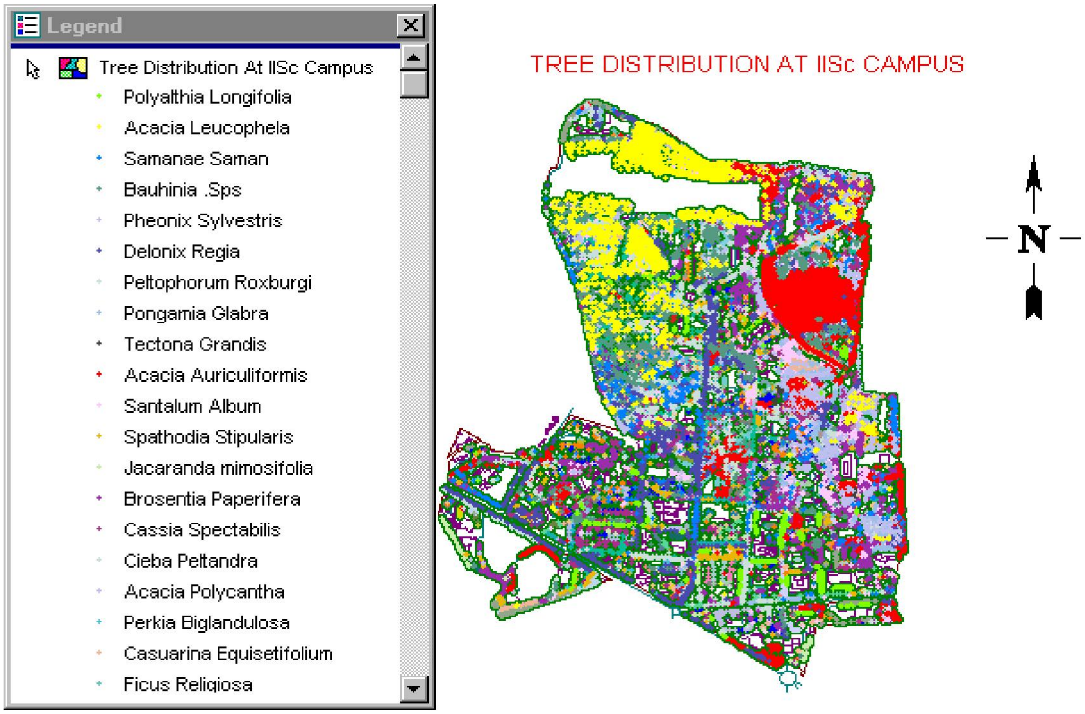

Figure 2: Tree distribution in IISc campus.

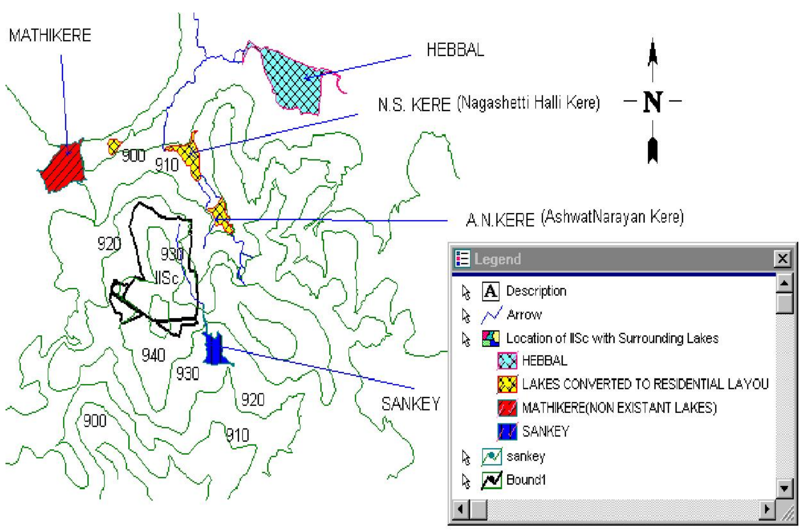

Figure 3: IISc campus bounded by the existing lakes.

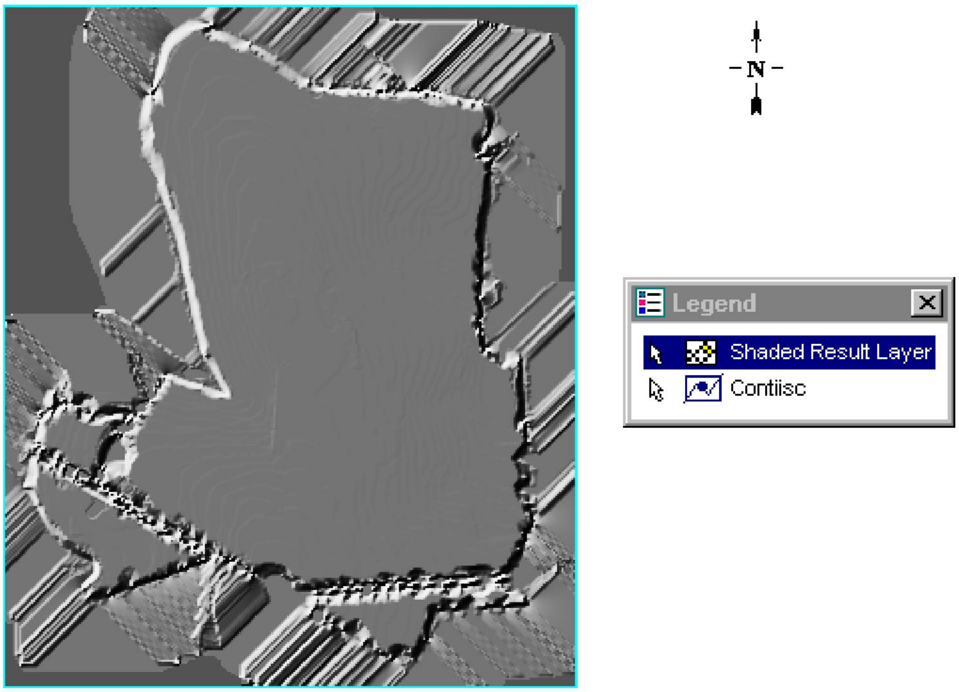

Figure 4: Digital Elevation Model of the IISc campus.

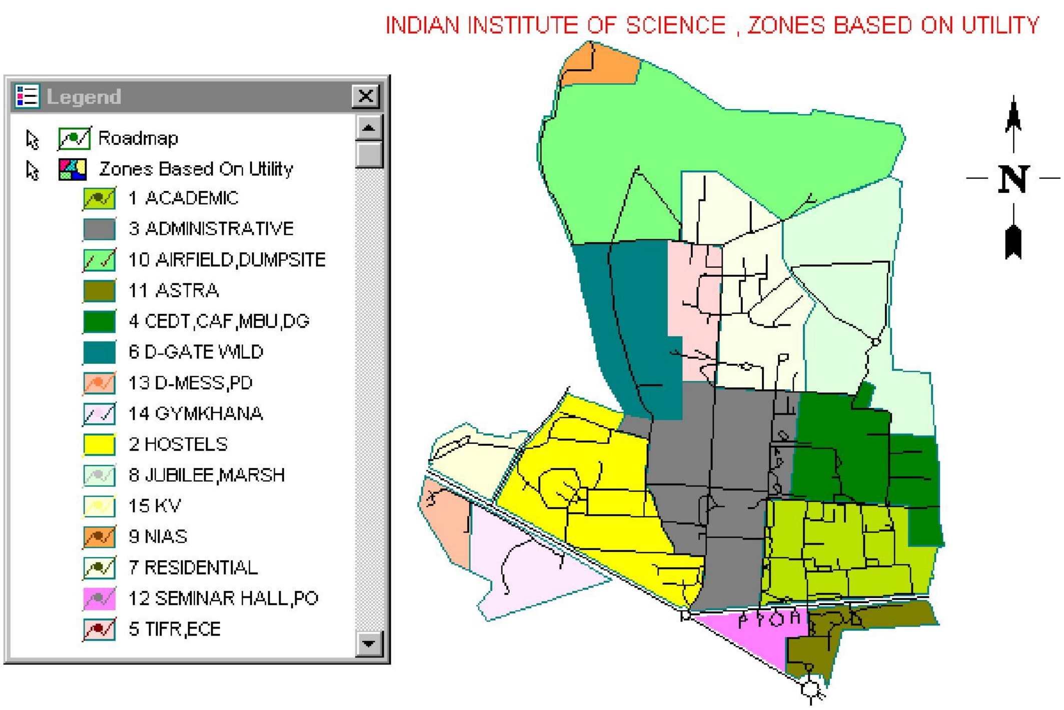

Figure 5: Land use map of IISc campus based on utility.

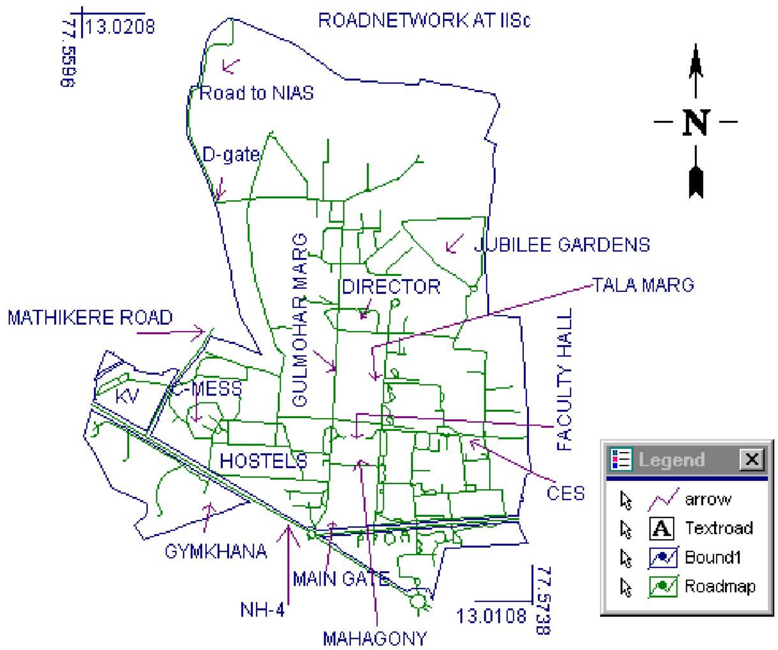

Figure 6: Road network of IISc campus.

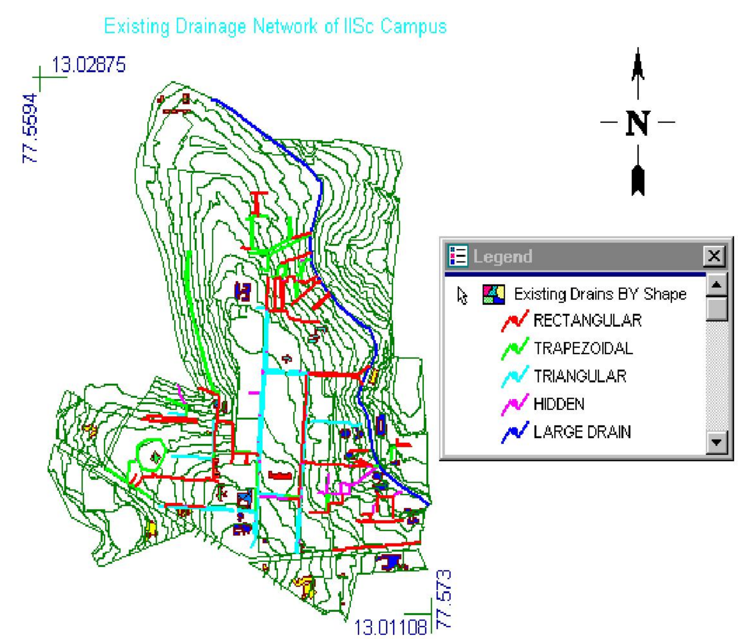

Figure 7: Drainage network of IISc campus overlaid on contours.

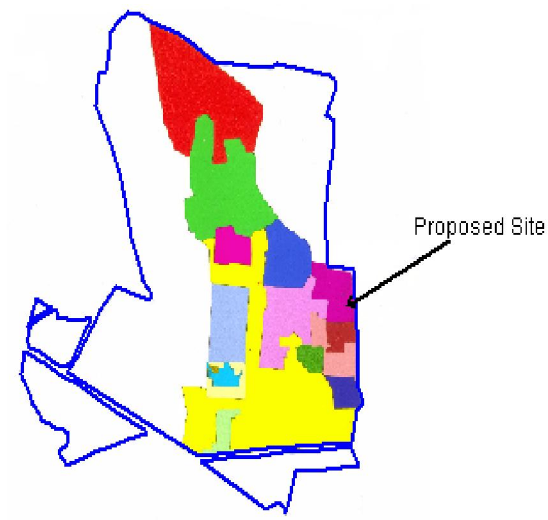

Figure 8: Rain Water Harvesting Site in IISc.

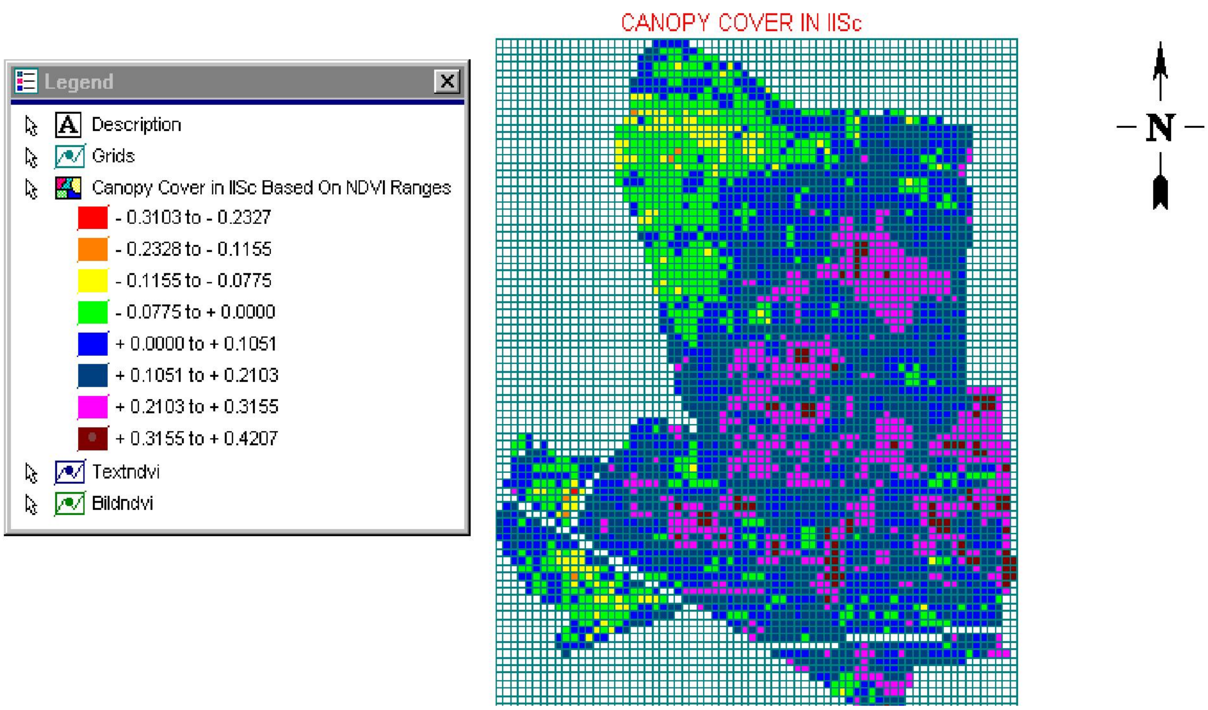

Figure 9: Canopy Cover of IISc Campus based on NDVI Ranges.

Mini forest at Indian Institute of Science: The Success Model for Rejuvenating Ecology and Hydrology in Rapidly Urbanizing Landscapes

1.0 Summary

<table>
<tr><td colspan="2">Characteristics: 49 tree species from central Western Ghats (Sirsi and Yellapur forests); Survival rate: 100%, Current number of tree species: 54</td></tr>
<tr><td colspan="2">Prominent Species: Mitragyna parvifolia (Roxb.) Korth., Chukrasia tabularis A. Juss., Duabanga grandiflora (Roxb. ex DC.) Walp., Garcinia indica (Thouars) Choisy, Holigarna grahamii (Wight) Kurz, Lophopetalum wightianum Arn. and Syzygium laetum (Buch.-Ham.) Gandhi</td></tr>
<tr><td>Area</td><td>About 1.65 – 1.75 hectares</td></tr>
<tr><td>Landscape characteristics before planting</td><td>Scrub vegetation infested with invasive weeds</td></tr>
<tr><td>Number of saplings</td><td>480 (belonging to 49 species)</td></tr>
<tr><td>Initial investment</td><td>Land preparation: Rs 12000
Transport of saplings from Uttara Kannada: Rs. 2400
Daily maintenance (regular watering, de-weeding, etc.) for the initial 36-40 months: Rs. 1,00,000 per year: Total Rs. 4,00,000
Fencing of miniforest region (to minimize external pressure): Rs 24500</td></tr>
<tr><td>Benefits</td><td>• Micro climate moderation (temperature at least 2 ^{0}C lower than the rest of the campus;
• Rain water infiltration and groundwater recharge;
• Improvement in groundwater table: The water table at this location was in the range of 60- 70 m depth before. The current level of water is at about 3 to 3.5 m below the ground. This indicates that land cover dynamics play a decisive role in recharging the groundwater sources. Other ecological benefits have resulted from creating the mini forest in the urban ecosystem are;

1. Improved campus microclimate with the reduced SO_4 and Suspended Particulate Matter (emissions of vehicles).</td></tr>
</table>

	2. Carbon sequestration, fruit, fodder etc. to dependent biota; 3. Reduced surface water runoff 4. Temperature in the vicinity at least 2 ºC and mitigation of urban heat islands 5. Improved air quality 6. Aesthetic value, reduction of storm water runoff, energy saving 7. Infiltration of rainwater, groundwater recharge, flood control 8. Wide array of micro habitats; 9. Habitat for diverse fauna. 10. Recreation and oxygen rich regions for urban population.
Individuals responsible for implementing Mini Forest Project at IISc	Dr. T.V. Ramachandra, CES, IISc Dr. Madhav Gadgil, CES, IISc Dr. C J Saldanha, CES, IISc
Staff involved in the development of mini forest	Regular watering (40 months), weed removal at initial stages – Mr.Venkatiah, Mrs. Venkatalakshmi Fencing, etc.: Raghavendra Rao, Manjunath B M, Venkatappa, Murugeshachar
Land Allocation and Support	Dr. C N R Rao, Director (1984-1994), IISc

2.0 Introduction: India is bestowed with the rich diversity of flora and fauna due to diverse landscapes. The species diversity has also helped in the selection of appropriate native species to enhance the ecological functions of urbanizing landscapes. Global warming and consequent impending danger of climate changes has necessitated to arrest deforestation. Adoption of monoculture plantations though the region appears green, but fulfilling the vital ecosystem functions such as groundwater recharge, food and fodder to dependent biota, etc. There is also a looming threat of climate change on food and water security in the country. This necessitates propagation of our native tree species to improve the micro climate, mitigation of floods, water security, etc, In this context, creation of miniforest was mooted three decades ago at the Centre for Ecological Sciences (CES), Indian Institute of Science (IISc), Bangalore and tree species of Western Ghats forests. This exercise also helped in evaluating the performance of Western Ghtas native plants in the Deccan plateau region - Bangalore. A small vacant space (about 1.75 hectare) that was beset with scrub vegetation (infested with invasive weeds – Parthenium) opposite to the CES in the campus of Indian Institute of Science was chosen for planting tree saplings from the forests of the Western Ghats. This region is now popularly known as IISc miniforest. Saplings (480 no's.) belonging to forty nine species (Table 1) which were raised at the CES Field Station Nursery at Sirsi, Uttara Kannada district and from forest divisions of Uttara Kannada district (Karntaka Forest Department, Canara Circle) were obtained and planted along with few species already existing on the plot with a spacing of 3 x 3 m.

Vegetation of Western Ghats: Western Ghats mountain ranges constitute the gorgeous array of mountains along the west coast of India, separating the Deccan Plateau and a narrow coastal strip (along the Arabian Sea). The mountain range starts from the southern part of the Tapti River near the border area of the states of Gujarat and Maharashtra. Western Ghats mountain ranges cover a length of around 1600 km (8° to 22° N, 73° to 78 °E) running through a geographical area of about 160,000 km^2 of Gujarat, Maharashtra, Goa, Karnataka, Tamil Nadu and Kerala states fin ally terminates at Kanyakumari district, in the southern-most tip of the Indian peninsula (Daniel, 1997). The climate is also extremely variable. The rainfall varies from 5000 mm per annum in windward areas to less than 600 mm in the leeward or rain shadow areas with prolonged dry season.

The vegetation varies broadly from evergreen, semi-evergreen, deciduous, scrub forests, sholas, grasslands and bamboo clumps. Factors including sunlight, rainfall, humidity, altitude, topography and location contribute to the uniqueness of this habitat, its animal and plant diversity. Plants species such as *Holigarna grahamii* (Wight) Kurz, Garcinia sp., *Mitragyna parvifolia* (Roxb.) Korth., *Lophopetalum wightianum* Arn., *Syzygium leatum* (Buch.-Ham.) Gandhi, *Entada rheedei* Spreng., *Calamus prasinus* Lak. & Renuka and the like represent evergreen, semi evergreen and moist deciduous species of the Western Ghats (Pascal and Ramesh, 1987, Pascal, 1988). These species generally thrive in Western Ghats with the unique climatic and edaphic factors and are not generally found thriving in other plateau regions.

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Mini Forest - An experiment to evaluate the adaptability of Western Ghats species for afforestation

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Abstract

Saplings of forty nine species of trees from Western Ghats forests were planted on a 1.5 hectare tract of Deccan plateau (in the campus of Indian Institute of Science, Bangalore) and their performance monitored for 23 years. The objective was to evaluate their adaptability to a habitat and conditions apparently alien to these species. The study was also meant to understand the linkages of these trees with the surrounding environment. Contrary to the belief that tree species are very sensitive to change of location and conditions, the introduced trees have grown as good as they would do in their native habitat and maintained their phenology. Further, they have grown in perfect harmony with trees native to the location. The results show that the introduced species are opportunistic and readily acclimatized and grew well overcoming the need for the edaphic and other factors that are believed to be responsible for their endemicity. Besides ex situ conservation, the creation of miniforest has other accrued ecosystem benefits. For instance, the ground water level has risen and the ambient temperature has come down by two degrees.

Keywords: Western Ghats, Ecological Services, Mini forest

It is general belief that tree species are adapted to such specialized natural conditions that they are unsuitable for translocation, particularly to planting in urban environs. Contrary to this opinion, it has been observed in the present study that trees have a remarkable ability to adapt to change in locations which are totally alien, a fact that was demonstrated by scores of exotic species naturalised and flourishing in parts of the world other than the region of their origin or nativity (Sankara Rao, 2008, 2009, Hanumaiah *et al*., 1967). There has been an almost continuous process of introduction of alien trees into Karnataka state, especially to Bangalore (Hayavadana Rao, 1930). The success of some of these is startling. They have come from a very wide range of geographic regions of the world. Within a short time, these species such as Paper mulberry (*Broussonetia papyrifera* Vent.), Tabebuias (*T. aurea, T. chrysotricha, T. impetiginosa, T. pallida, T. rosea*), Leucaena (*Leucaena latisiliqua* (L.) Gillis) and some Australian Acacias (*Acacia auriculiformis* Cunn. ex Benth.) have come to dominate Bangalore's tree flora and become the principal cause for a number of native species in the city edging towards local extinction. There is a growing concern that we should be helping to maintain our native woodland species in afforestation programmes in denuded land and in cities which are suffering from a continuous process of attrition, particularly in the urban spaces in the face of modern developments.

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Flora of India belongs to diverse vegetation types. Virtually every kind of vegetation supported tree species, small and big, deciduous and those that remain leafy most part of the year. The species diversity is enormous and as such, there is no dearth for selection of species among these native trees for afforestation and urban greening. There is also the impending danger of climate change, which is likely to affect some of our native tree species, and their phenology, and thereby effecting further regeneration and continuity of the species, which would result in loss of diversity. It might therefore become necessary to bring different wild indigenous species to other locations and also into city confines where they might have better opportunity to thrive under a watchful eye. With this conservation strategy in mind, creation of miniforest was mooted three decades ago at the Centre for Ecological Sciences (CES), Indian Institute of Science (IISc), Bangalore and tree species of Western Ghats forests were sought to be evaluated for their performance in the Deccan plateau region of which Bangalore is a part. A small vacant space (about 1.5 hectare) that was beset with scrub vegetation opposite to the CES in the campus of Indian Institute of Science was chosen for planting tree saplings from the forests of the Western Ghats that came to be known as the miniforest. Saplings (480 no's.) belonging to forty nine species (Table 1) which were raised at the CES Field Station Nursery at Sirsi, Uttara Kannada district were obtained and planted along with few species already existing on the plot with a spacing of 3 x 3 m.

Figure 1: Picture showing the type of terrain on which the miniforest was raised

Table 1: List of species in the miniforest

Sl No	Species
1	*Adenanthera pavonina* L.
2	*Adina cordifolia* (Roxb.) Hook.f. ex Brandis
3	*Ailanthus triphysa* (Dennst.) Alston
4	*Albizia amara* (Roxb.) Boiv.
5	*Alstonia scholaris* (L.) R. Br.
6	*Areca catechu* L.
7	*Artocarpus heterophyllus* Lam.
8	*Artocarpus hirsutus* Lam.
9	*Artocarpus lacucha* Roxb. ex Buch.-Ham.
10	*Bambusa arundinacea* (Retz.) Willd.
11	*Bombax malabaricum* DC.
12	*Broussonetia luzonica* Bureau
13	*Butea monosperma* (Lam.)Taub.
14	*Calamus prasinus* Lak. & Renuka
15	*Calophyllum apetalum* Willd.
16	*Calophyllum inophyllum* L.
17	*Cananga odorata* (Lam.) Hook. f. & Thoms.
18	*Canarium strictum* Roxb.
19	*Ceiba pentandra* (L.) Gaertn.
20	*Chukrasia tabularis* A. Juss.
21	*Commiphora wightii* (Arn.) Bhand.
22	*Duabanga grandiflora* (Roxb. ex DC.) Walp.
23	*Elaeocarpus serratus* L.
24	*Elaeocarpus tuberculatus* Roxb.
25	*Entada rheedei* Spreng.
26	*Ficus benghalensis* L.
27	*Ficus racemosa* L.
28	*Garcinia indica* (Thouars) Choisy
29	*Holigarna grahamii* (Wight) Kurz
30	*Holigarna arnottiana* Hook. f.
31	*Hopea ponga* (Dennst.) Mabb.
32	*Lagerstroemia lanceolata* Wall. ex C. B. Clarke
33	*Lophopetalum wightianum* Arn.
34	*Madhuca longifolia* (Koenig) Macbr.
35	*Mallotus philippensis* (Lam.) Muell.-Arg.
36	*Mangifera indica* L.
37	*Memecylon umbellatum* Burm. f.
38	*Mimusops elengi* L.
39	*Mitragyna parvifolia* (Roxb.) Korth.
40	*Pajanelia longifolia* (Willd.) K. Schum.
41	*Sterculia guttata* Roxb. ex DC.
42	*Syzygium cumini* (L.) Skeels
43	*Syzygium laetum* (Buch.-Ham.) Gandhi
44	*Terminalia arjuna* (Roxb. ex DC.) Wight & Arn.
45	*Terminalia crenulata* Roth
46	*Vateria indica* L.
47	*Vitex altissima* L.f.
48	*Xylia xylocarpa* (Roxb.) Taub.
49	*Ziziphus rugosa* Lam.

The area encompassing Western Ghats is recognised as one of the most eco-sensitive regions of the world and is one among the 34 biodiversity hotspots on the basis of its species richness (Myers, *et al.*, 2000).

Western Ghats run along the West coast of India from the Vindhya-Satpura ranges in the North to the southern tip of the peninsula to a stretch of 6000 km, covering an area of nearly 1, 59,000 sq. km and consist of mountains ranging from 50 m to 2695 m in height. Western Ghats receive an average of 6000 mm of rainfall every year. The vegetation is quite diverse, broadly having evergreen, semi-evergreen, deciduous, scrub forests, sholas, grasslands and bamboo clumps. Factors including sunlight, rainfall, humidity, altitude, topography and location contribute to the uniqueness of this habitat, its animal and plant diversity. Plants such as *Holigarna grahamii* (Wight) Kurz, *Garcinia sp.*, *Mitragyna parvifolia* (Roxb.) Korth., *Lophopetalum wightianum* Arn., *Syzygium leatum* (Buch.-Ham.) Gandhi, *Entada rheedei* Spreng., *Calamus prasinus* Lak. & Renuka and the like represent evergreen, semi evergreen and moist deciduous species of the Western Ghats (Pascal and Ramesh, 1987, Pascal, 1988). These species generally thrive in Western Ghats with the unique climatic and edaphic factors and are not generally found thriving in other plateau regions.

It is observed that in less than 25 years, the experimental plot, now termed 'Miniforest' on account of the limited area, is transformed into a lush green forest on a terrain that was originally a scrub vegetation of the Deccan plateau type with apparently conditions alien to most of the species that have been introduced. The miniforest, in this respect, presented an opportunity to study the adaptations and succession of the Western Ghats forest species (Table 1) in comparison with native species existing in the area. The species composition that emerged in the experimental plot is quite interesting. Majority of them are the Western Ghats species whereas the others, the native to scrub vegetation, both found growing in perfect harmony, in spite of the difference in rainfall (850 mm), humidity, temperature and soil conditions for the former species (Fig 2). The miniforest trees exhibited normal robust growth, flowered and set fruit as they would do in their native habitat. Some of the trees, for example *Mitragyna parvifolia* (Roxb.) Korth., *Chukrasia tabularis* A. Juss., *Duabanga grandiflora* (Roxb. ex DC.) Walp., *Garcinia indica* (Thouars) Choisy, *Holigarna grahamii* (Wight) Kurz, *Lophopetalum wightianum* Arn. *and Syzygium laetum* (Buch.-Ham.) Gandhi (Plate 1) have grown as well as they would do in the evergreen forests.

Figure 2: A view of Miniforest

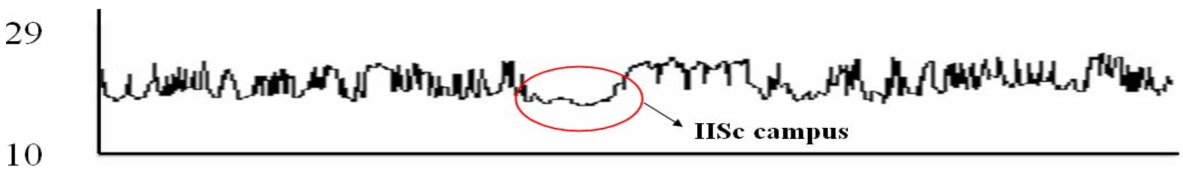
A gigantic liana *Entada rheedei* Spreng., that was not known to grow outside the moist forests has thrived very well and spread prolifically to nearby areas (Ramesh Maheshwari et al., 2009) and flowered since 2001(Fig 3). *Calamus prasinus* Lak. & Renuka, being a rattan, which is rarely reported to survive in drier tracts, has also grown considerably well exhibiting normal flowering (Gopalakrishna Bhat, 2003). These observations provide evidence that most of the trees of the Western Ghats forests are opportunistic and grow under factors largely different from those believed to be responsible for their endemicity. A microclimate prevails in the plot, the miniforest. There is a slight dip in temperature, an increase in humidity and humus enrichment on account of the survival of many moist evergreen species and their good canopy cover. The miniforest plot is kept undisturbed. Progressively, the area developed rich micro- and macro-fauna, from insects, frogs, snakes to birds and smaller mammals like the most elusive Slender Loris. Smaller plants such as mosses, algae, fungi, ferns, herbaceous plants and climbers have grown well adapting to the change. The entire plot is amazingly transformed into the type of a habitat that prevails in the moist forests of Western Ghats.

Other ecological benefits have resulted from creating the miniforest. Temperature profile analysis through the computation of Land Surface Temperature (LST) was carried out using LANDSAT ETM thermal data shows that the temperature in this area is at least 2 degrees lower than the surrounding regions (Fig 4). The water table at this location was in the range of 60-70 m depth before creating the miniforest. Present monitoring of water table shows the level of water is

Figure 3: A gigantic liana *Entada rheedei* Spreng.(with fruits)

at about 3 to 3.5 m below the ground. This indicates that land cover dynamics play a decisive role in recharging the groundwater sources. Four families of Slender Loris (*Loris tardigradus*) inhabiting here is an indication of total wilderness prevailing in the miniforest, further confirming the ecological richness of the habitat.

Figure 4: Temperature profile of IISc campus (Transect passing through miniforest)



***Syzygium laetum* (Buch.-Ham.) Gandhi**

***Lophopetalum wightianum* Arn**

***Holigarna arnottiana* Hook. f. (Fruiting)**

***Garcinia indica* (Thouars) Choisy (Fruiting)**

Figure 5: Evergreen species of miniforest

The results further show that the experiment of the miniforest can be replicated to create such green pockets in and around other urban spaces. This kind of green patch not only can be an arboretum for evergreen tree species but also serves as a home for several refuge fauna and adaptable species. The patch will also serve as an efficient carbon sink, trapping free carbon in the atmosphere, bringing the temperature to less than a degree, thus helping in mitigating climate change issues. Similar experiments also can be valuable in establishing germplasm banks to offset any loss of species in the wild due to climate change and other factors.

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In this issue

A giant liana in an alien environment

A liana is a plant requiring physical support for its weak stems to climb a host tree for maximizing photosynthesis. Lianas epitomize tropical rain forests but because of the difficulty in research in conditions of high rainfall and dense vegetation, lianas have remained poorly studied. To

initiate research on various aspects of liana biology seeds of a leguminous liana *Entada pursaetha* were collected from coastal region and sown inside a research campus in a dry subtropical region. In 17 years a single seedling has grown into a giant liana, perhaps the largest recorded. Though its unchecked spread in the campus has caused problems requiring pruning, the availability of a liana inside a campus opens up several opportunities for research, including the diversity in the morphology of the liana branches, the biomechanics of the upright trunk constructed by anticlockwise coiled branches uncoiling at breast height into highly twisted spreading branches that lean on support host trees, the mechanism in hydraulic supply, and navigation by the aerially formed leafless shoots that have spread its canopy on surrounding trees. The vigour of the introduced liana in an alien environment raises the question as to why this liana is confined to the coastal areas or the river banks. The large seeds of this liana remain dormant due to hard seed coat. Water may be required for the dispersal of the seeds, and also for softening the seed coat by lytic enzymes released from the aquatic microorganisms. See **page 58**.

Large branchiopods

The special section is the outcome of the Sixth International Large Branchiopods Symposium organized by the Acharya Nagarjuna University, Nagarjuna Nagar, in September 2007 at Vijayawada (see *Curr Sci*., 2008, **94**, 164–165). As a major class of Crustacea, the branchiopods are comprised of calm shrimps, fairy and brine shrimps and tadpole shrimps. They inhabit unstable ephemeral inland and brackish waters. Describing the distribution of 35 species of clam shrimps in India, M. K. Durga Prasad and G. Simhachalam (**page 71**) indicate the endemicity of 32 species. Summarizing his 20 years of intense field studies, B. V. Timms (**page 74**) explains the unusual species richness and the amazing halophilic branchiopods of Australia. Using molecular markers, R. Tizol-Correa *et al.* (**page 81**) trace the phylogenetic relationships of the brine shrimps from tropical salt-pans of Mexico and Cuba. From an experimental interspecific hybridization study of the African fairy shrimps, H. J. Dumont and Els Adriaens (**page 88**) report that the rate of evolution in these fairy shrimps has remained unusually slow.

To tide over the unfavourable dry season, these animals adopt different patterns of reproduction; some are bisexual, while others display a wide range of sexuality and modes of reproduction. In the Mexican waters, H. Garcia-Velazco *et al.* (**page 91**) record the occurrence of parthenogenetic females and cross-fertilizing hermaphrodites in the tadpole shrimp population. From an experimental study, S. C. Weeks (Akron University, USA, **page 98**) suggests that males introduced into the population by an amphigenic hermaphrodite can be sustained for a few generations.

These creatures are also capable of generating drought-resistant cysts; for instance, the cysts of the brine shrimp alone are known to synthesize and store two unique hitherto unknown proteins called Artemin and p26. These proteins withstand the thus for unknown minimal residual water of 0.7 μg/g cyst and when hydrated (1 million times) 0.7 g water/g cyst. N. Munuswamy *et al.* (**page 103**) have recorded their presence in the cysts of the Indian fairy shrimp. Besides this, the branchiopods adopt a sort of bet-hedging strategy by hatching only a cohort of the accumulated cysts bank, when pools are filled with rainwater.

All developing countries practising aquaculture import *Artemia* cysts from USA. For instance, to feed 1000 million hatchings of shrimp cultivated for export, India imports 100 tonnes of *Artemia* cysts at the cost of Rs 560 million. Some companies fill up deliberately commercial brine shrimps cysts with different shrimp species and thereby introduce unsolicited *Artemia*, which may hybridize with native species. To identify such a 'contaminant', R. Campos-Ramos *et al.* (**page 111**) describe a bio-kinetic range of cyst-hatching temperatures for *Artemia* spp. C. Arulvasu and N. Munuswamy (**page 114**) have shown that *Artemia* nauplii can also be enriched with growth-promoting polyunsaturated fatty acid by soaking the larvae in 0.5% shrimp head oil emulsion for a period of 9 h. In an ingenious study, C. Orozco-Medina *et al.* (**page 120**) have shown that the metanauplii of *Artemia* ingested bacterial cells. Thus, the special section highlights the academically interesting and economically useful large branchiopods.

T. J. Pandian
N. Munuswamy
—*Guest Editors*

Structural characteristics of a giant tropical liana and its mode of canopy spread in an alien environment

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To circumvent the practical difficulties in research on tropical rainforest lianas in their natural habitat due to prevailing weather conditions, dense camouflaging vegetation and problems in transporting equipment for experimental investigations, *Entada pursaetha* DC (syn. *Entada scandens* Benth., Leguminosae) was grown inside a research campus in a dry subtropical environment. A solitary genet has attained a gigantic size in 17 years, infesting crowns of semi-evergreen trees growing in an area roughly equivalent to 1.6 ha. It has used aerially formed, cable-like stolons for navigating and spreading its canopy across tree gaps. Some of its parts which had remained unseen in its natural habitat due to dense vegetation are described. The attained size of this liana in a climatically different environment raises the question as to why it is restricted to evergreen rainforests. Some research problems for which this liana will be useful are pointed out.

Keywords: *Entada*, lianas, natural habitat, plant growth, rainforest.

A LIANA is a woody plant which is rooted in the ground, but needs the physical support of a nearby tree for its weak stem and branches to lean and ascend for exposing its canopy to sunlight. Based on transect sampling in rainforests, it has been estimated that climbers or lianas comprise about one-fifth of all plant types[1] (trees, shrubs, herbs, epiphytes, climbers, lianas and stragglers). Investigations on lianas in tropical rainforests are hindered by dense vegetation; even their gross morphology has neither been adequately described nor illustrated. Therefore, if a rainforest liana can be successfully grown in a research campus, this can be considered a breakthrough as opportunities can be opened up for various types of research – such as biomechanical characteristics of its specific parts, tropic responses, host preference, climbing mechanism, nitrogen fixation, type of photosynthesis (C3 or C4), root pressure, reproductive biology, mechanism in invasive growth and morphological response upon contact with support trees. With these objectives, seeds of *Entada pursaetha* (Mimosoideae, Leguminosae) were sown in a research campus in Bangalore – a city in Deccan Plateau – with an average elevation of 918 msl and mean annual precipitation of 950 mm, chiefly during the monsoon period from July to October. A single plant has unexpectedly attained a gigantic size in less than 17 years, with its canopy infesting the crowns of nearby trees. Although data on the ontogenetic changes of this genet are unavailable because of the passage of time, we attempt an interpretation of its growth characteristics and reconstruct the events in *Entada* development from its extant morphological organization. We point out some questions vital to understanding the evolution of the lianoid forms.

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Materials and methods

Entada pursaetha DC has been reported from Silhet (now Bangladesh), Manipur, the Andamans and Nicobar Islands and the Eastern and the Western Ghats in peninsular India[2–4]. Seeds of *Entada* were collected from the Western Ghats (lat. 13°55′–15°31′N, long. 74°9′–75°10′E) about 55 km from the Arabian Sea, at an elevation of 700–800 msl. The region receives 450 cm or more annual rainfall, and during post-monsoon period the wind speed is 8–10 m/s. Following mechanical cracking of the hard testa, the seeds were kept in a coarse cloth bag and floated in pond water for about 20 days before sowing at various places in the campus. Of the seven seeds sown, one buried in the soil close to a tree of *Bauhinia purpurea* (Caesalpinioideae, Leguminosae) has grown into a liana, spreading its canopy on a miniforest of the semi-evergreen tropical trees, in an area roughly equivalent to 1.6 ha. Since its climbing parts are mostly hidden among the crowns of support trees, locating their interconnections and estimating the spread area of this liana required observations over a period of time, especially when the identity could be confirmed by examination of its flowers and fruits. Here we focus on some features of *E. pursaetha* (hereafter referred to as *Entada*) of value to liana biology.

Figure 1. The tree-form of *Entada pursaetha*. ***a***, Self-supporting trunk (thick arrow) in proximity to *Bauhinia purpurea* (Leguminosae). The pleats comprising upright trunk uncoil at or above breast height (thin arrow) and diverge as separate branches (thin arrows) that lean on the surrounding support trees. ***b***, Festoons of secondary branches suspended from support trees. *Entada* has overtaken and oversized *B. purpurea*.

Results and discussion

The superstructure of *Entada* is comprised of a mix of structures of a tree and a woody climber, and some unique structures. Its erect trunk is comprised of anti-clockwise-twisted pleats. Its climber part comprises of hammock-like, twisted, woody stems. The structure that has spread its canopy from one support tree to another are long, leafless, cable-like stems (stolons) that navigated aerially approximately 15 m above the ground, differentiating foliage upon accessing a living tree.

Freestanding trunk

The *Entada* trunk has a girth of 2.1 m at the base and 1.7 m at breast height and is organized as helically twisted pleats (Figure 1 *a*). Although we missed out the ontogenic changes, the self-supporting trunk may have resulted from orthotropic vegetative offshoots that developed from the base of the sapling. This is plausible because according to the noted researcher of rainforests, P. W. Richards[5], 'tropical rain-forest trees often produce coppice-shoots very readily when the main trunk has fallen or decayed … a new formation of coppice-shoots grows up round the secondary main trunk'. We assume that in its juvenile phase *Entada* formed circumnutating offshoots from the base, allowing mutual contacts and eventually fusing to form a mechanically-independent trunk. Circumnutation is a common property in climbers that enables contacting a potential support in the vicinity[6–8]. Sectioning of this solitary specimen for wood anatomy was not possible. However, a reason for considering the *Entada* trunk as comprised of basally formed conjoined, offshoots is because the pleats unwind at 1.5–3 m above the ground and diverge as branches either in vertical or horizontal directions. No other liana is known with a trunk constructed similarly, although the Neotropical liana *Croton nuntians* (Euphorbiaceae) in French Guyana is freestanding and resembles a young tree, but becomes unstable and leans on surrounding vegetation for support[9].

Anticlockwise twists in climbing parts

The uncoiled trunk pleats have branched out into hammock-like, highly twisted, woody branches (Figure 1 *b*). Yet, no above-ground part has twined around a support tree or its branches; hence *Entada* is not a twiner. Rather, its branches mostly lie on the host branches for support and are occasionally entangled into them. A striking feature of *Entada* are the climbing branches shaped into an 'Archimedes screw' (Figure 2) with pronounced tangential thickening. The significance of this patterning is unknown. Recently, a theory has been put forward for the formation of twists in stems subjected to bending stress[10].

The predominantly anticlockwise helices in *Entada* prompted us to examine the direction of coiling in climbers growing in a nearby miniforest in the campus. Anticlockwise ascend was observed in all climbers. Edwards *et al.*[11] reported anticlockwise twining in plants at 17 sites in nine countries in both the northern and southern hemisphere. An exception is the yam *Dioscorea*, where species have been classified on the basis of stems twining to the left or to the right[12]. The handedness of growth depends on the orientation in which cortical microfibrils are organized under the control of *spiral* gene[13]. However, it is not known whether helical microtubule arrays are the cause or the consequence of organ twisting.

We have not observed any thorns, hooks, spines or stem tendrils that could facilitate anchoring of *Entada* to the supporting tree. Rather, physical support is gained by occasional placing of its branches on those of support trees. At best, *Entada* may be classified as a straggler.

Figure 2. The climber-form of *E. pursaetha*. ***a***, Hammock-like branches with twists (arrow). ***b***, Major types (arrows) of branches, numbered 1 to 4. Note Archimedes screw patterning in branch # 3.

Figure 3. ***a***, *Entada* in a decumbent orientation against a wall is distinguished from other species of woody climbers by white and yellow inflorescence. ***b***, A 2 ft long pod.

Some of its overhanging leafy branches that were exposed to full sunlight during March–April (before monsoon rains begin) produced inflorescence (Figure 3).

Invasion and spreading strategy

Thus far, all previously reported lianas spread their canopy by means of ground stolons which then climb on available support. *Entada* is unique: it has formed specialized, cable-like, aerial stolons (Figure 4) that have extended near-horizontally into air, crossing gaps and spreading canopy from the primary support tree onto the crowns of other support trees (Figure 5). The length of these aerial stolons exceeds 15 m; and there is no evidence of a support tree being present between the inter-support distances, because of a dividing tarred road. Hence investigations are required as to how *Entada* sensed the availability of support trees across tree gaps, the time and rate of elongation of stolons and the chemical cues directing their aerial trajectory towards the available crown. Indeed, it was the aerial stolons traversing a road junction over a lamp post which attracted the attention of two authors to an unusual plant type growing in the campus. Following contact with the crown of support trees, the stolons have branched and much of their twisted woody branches appear to support each other (self-support), with this being augmented by the branches that have infiltrated into the trees. A stand of bamboo culms accessed across a gap due to a road is bent down to a greater degree than the uninfested culms, either because of the weight of *Entada* or because *Entada* exerted a force to pull them down. Structural adjustments that are required to counter stress and strain as a consequence of tension due to pull need investigation.

Figure 4. Mode of spread in *E. pursaetha*. ***a***, Leafless aerial shoots navigating across a gap towards tree canopy. ***b***, Horizontally extending shoots traversing a gap between trees and bypassing an inanimate support (lamp post) in a road junction in their trajectory towards living trees. Since this photograph was taken, the aerial stolons (cable-like stems) have been cut as these were posing a hazard to vehicular traffic.

Figure 5. Invasive growth. Aerial stolon (arrow) crossing tree gap to spread on crown of tree canopy.

Since the aerial stolons are oriented towards a vegetated tract across a tarred road without crisscrossing (Figure 4), a possibility is that other than phototropism, some volatile chemicals produced by the 'host' trees not only provided a cue for the development of cables, but also directed their extension towards trellises. This speculation is supported by a recent finding that volatile compounds, α-pinene, β-myrcene, 2-carene, *p*-cymene, β-phellandrene, limonene, (*E*,*E*)-4,8,12-trimethyl-1,3,7,11-tridecatetraene and an unidentified monoterpene released by tomato plant guide the dodder vine, *Cuscuta pentagona*[14]. Rowe and Speck[15] have illustrated 'searcher branches' in a woody liana *Strychnos* sp. (Loganiaceae), having a cable-like appearance and extending horizontally 3–4 m across the canopy gap to locate new support. Upon contact with a neighbouring tree, the *Entada* cables (stolons) differentiated normal foliage, viz. compound leaves with thick leaflets. The branches of *Entada* have infiltrated and entangled with that of *Bauhinia purpurea*, *Cassia spectabilis*, *Broussonetia papyrifera*, *Tebebuia rosea*, *Eucalyptus tereticornis*, *Tectona grandis* and *Bambusa* sp. However, we have not observed *Entada* on dead branches of standing trees, raising the possibility of requirement of living support trees for infestation. Since coiling, bending or flexing and differentiating into morphologically distinct parts occur in response to contact, the phenomenon of thigmomorphogenesis appears to be important in the infiltration and spread of *Entada* on living trees.

We have not observed new cables (aerial stolons) being formed in the four years since regular observation of *Entada*, suggesting that there could be periodicity of years in triggering its development. Some bamboos behave similarly[16]. A contentious explanation is that the aerial stolons were formed in response to some unusual weather trigger. Perhaps, more likely is periodicity in their development. Possibly these were stiff as the culms of bamboo, and extended rapidly across tree gaps. Based on an estimate of its spread size and the timescale, it appears that *Entada* could be amongst the fastest growing plants; rivalling the bamboos in which the culms grow almost 4 ft in a 24 h period (www.lewisbamboo.com/habits.html). The fast growth rate of stolons against gravity will enable them to take mechanical risk[17].

Cable-like stolon along the ground surface with ascending apex was illustrated in a palm *Desmoncus orthacanthus*, growing in the rainforests in South America[18] and in rhizomatous shrub *Xanthorhiza simplicissima*, growing in the Botanical Garden in Freiburg, Germany[19]. However, data on its rate of extension was not given. Penalosa[7] reported a liana *Ipomoea phillomega* in the rainforest of Mexico, with leafless, creeping stems (stolons) on the ground that extend up to 30 m at a mean rate of 13.6 cm/day, and turning upwards in a *S*-shaped manner upon contact with a potential support and twining around a support host in sunny clearings. The climber *Clematis* *maritima* changes its morphology when growing on aboveground areas and on sand[17]. We have not observed surface-growing stems in adult *Entada*. Its aerial stolons changed morphology upon accessing a support tree, suggesting that in addition to light and circumnavigational movement, contact-induced differentiation of foliage is important in mechanistic explanation of *Entada* spread on crowns of support trees as a straggler. Trellis availability is a major factor determining the success of canopy-bound lianas[20].

Hydraulic supply

The parent and the interconnected daughter canopies of *Entada* are founded on a single germinated seed and hence on a single root system. Since the aerial stolons ultimately connect to the rooted trunk, these must constitute the hydraulic system for the entire canopy.

When aerial stolons (cables) extending across a road junction, posing hazard to motorists were cut, colourless, watery sap trickled from the cut cables. This suggests that water is translocated by root pressure, requiring development of non-destructive methods for investigation of its underground parts. Apparently, the twists in plant structure do not resist the movement of water, making *Entada* a good material for investigations of pressure-generating capability for water movement, compared to a tree. Following severing, the daughter canopies differentiated by aerial stolons and distributed on surrounding trees dried, confirming that the aerial cables constitute the hydraulic supply system and the structural form for the spread of the canopy on support trees.

Ecophysiology

Occasionally, a terminal leaflet in the pinnate compound leaves of *Entada* is modified into a forked tendril (Figure 6 *b*). Tendril development may be influenced by the amount of light filtering through the canopy, and its function may only be to orient the leaf for maximal absorption of sunlight by the canopy in natural habitat under cloudy conditions. A visual comparison of the density of *Entada* foliage with that of the surrounding trees suggests that this liana invests more of photosynthetically fixed carbon in woody branches, which have a capacity to resprout after breakage.

The first sighting of a single 12 inches long, green pod was in May 2003, and again in 2005 and 2008. It therefore appears that fruiting in the alien environment is a rare phenomenon, for unknown reasons. Although being a leguminous plant, *Entada* is assumed to be self-pollinated, the lack of a pollinator species could account for its rare fruiting. Further observations are required to determine if flowering and fruiting in the daughter canopies is synchronized with that of the interconnected parent canopy. Brandis[2] described fruits of *E. pursaetha* as 2–4 ft long and 3–4 inches broad. An *Entada* pod in the Phansad Wildlife Sanctuary (about 152 km from Mumbai) was found to be nearly 6 ft long. *Entada* pods are therefore among the largest legumes.

The ability to produce large pods with rather large seeds[2,3] suggests a high photosynthetic rate. It is believed that lianas have a fast growth rate because of their high photosynthetic rate due to elevated CO_2 in the canopy[21]. Contrary to popular belief, liana density and growth are unrelated to the mean annual precipitation[19,21,22]. Schnitzer[22] reported that lianas grow nearly twice as much as trees during the wet season, but more than seven times that of trees during the dry season. This observation was corroborated by Swaine and Grace[23]. In view of the requirement of seedling material for experimental investigations in the laboratory, the reproductive biology of *Entada* assumes special importance.

Regeneration

Aerial stolons (diameter approximately <10 cm) that had begun to cause obstruction to vehicular traffic were cut. Two to four metre long cut pieces of woody stems (diameter 20–30 cm) were gathered and left in the open. In about 4 weeks the cut stems sprouted one to 1½ m tall shoots with stiff, erect stems producing foliage (Figure 6). Since sprouting occurred during the dry season, this observation signifies that *Entada* stores considerable water inside the stem tissue. However, the cut stems did not root, and the sprouts dried after the rains ceased. However, the ability of cut stems to resprout has implication in its natural habitat where strong wind and rain prevail: The branches that are unable to resist wind-induced breakage or those that are unstable under their own weight may fall on the ground and function as ramets (vegetatively produced, independent plants). This raises the question of the specific contribution of the ramets (broken and fallen branches that resprout and form roots) versus the genets (single individual plants from sexually formed seeds) in the composition of *Entada* thickets in its natural habitat. In Panama, Putz[20] noted the propensity for lianas to sprout vigorously from fallen stems. Based

Figure 6. Regeneration in *E. pursaetha*. ***a***, Sprouting of shoots in cut, aerial stolons and attached branch. ***b***, Forked leaf tendril (arrow) showing anticlockwise twining.

Table 1. Summary of salient characters of *Entada pursaetha*

Observation	Phenomenon implied
Seeds required scarification and incubation in pond water for germination	Mechanical dormancy
Free-standing, upright trunk formed by conjoining of basally sprouted branches	Circumnutation of coppices and thigmomorphogenesis
Anticlockwise twists throughout mature plant body	Morphological plasticity
Branches lean on support trees	Discrimination of living support?
Navigation towards canopy of support trees across large gaps by leafless aerial stolons (remote sensing)	Perception of chemical cues
Time taken by genet to spread canopy on neighbouring trees <17 yrs	Rapid growth
Aerial stolons produce foliage following contact and infiltration into support trees	Thigmomorphogenesis
Infrequent fruiting despite profuse flowering	Dependency on a pollinator?
Pod >2 ft, seeds large	High photosynthetic rate, large maternal investment
Terminal leaflet modifies into tendril	Interception of light filtering through canopy and response to quantity and quality of light
Maintained greenness and spread over 1.6 ha despite seasonal drought	Deep root system, high root pressure

Table 2. Research problems for which an introduced *Entada* can be especially valuable

Research area	Description
Biological species invasion	Tracking the timetable, speed for navigation of aerial stolons towards support trees. Navigation of aerial stolons – evidence for chemical cues.
Plant biomechanics	Measurement and comparison of root pressure, transpiration rate, ascent of water to canopy, causes of anticlockwise twists and helical geometry and flexural rigidity of stems, xylem architecture and water transport, and correlation of anatomical parameters of different stem types with structural bending modulus. Reasons for the formation of 'screw' type reaction wood (Figure 2).
Plant morphogenesis	Mechanoperception of support trees and differentiation of foliage, germination of seeds, seedling morphology, and role of circumnutation behaviour in seedling for construction of self-supporting trunk.
Plant physiology, horticulture	Rooting of ramets, growth rate and response to light, estimation of compensation point.
Plant population genetics	DNA analysis for differentiation of ramets versus genets
Plant microbiology	Benefit from nitrogen-fixing ability. Possible benefit to trellises from symbiotic nitrogen-fixing ability of leguminous liana
Plant reproductive biology	Causes of irregular fruit set, quantitization of viable seeds produced/individual
Ecophysiology	Mechanisms in photosynthetic acclimation to light changes in canopy because of density of foliage, determination of compensation point
Plant ecology	Periodicity in formation of navigating aerial stolons, timetable of their development and speed of extension, the estimation of life-span, comparative analyses of inorganic nutrients (N, P, K, Ca, Mg) in soils in the campus and the wetlands (natural habitat).

on seedling excavations, Putz found that 90% liana species in the understorey were ramets.

Paradox of growth in alien environment

The factors that may explain an alien liana thriving in a place which receives only about 95 cm annual rainfall and where the soil surface (red earth) is generally dry, except for the monsoon months (May–September) are:

(1) Foremost, a safe mode of infiltration on available support trees by means of aerially formed stolons, thereby avoiding risk of injury from trampling by grazing animals.

(2) Nutrient-rich soil in the campus (the soils in rainforests is generally nutrient-poor because of the leaching of nutrients by rains through the millennia[5,24]).

(3) Presumed deep root system of *Entada* allowing access to water table, or water which seeped down from a

nearby stream. This is in keeping with a report[25] that root systems in excavated liana seedlings of *Davilla kunthii* (Dilleniaceae) in eastern Amazonia were more than eight times longer than the aboveground stem.

(4) Higher solar illumination[26].

(5) Absence of herbivores or pathogens and less competition for resources as more area is available for aerial spread, root growth and nutrient absorption, unlike in dense vegetated tropical forests.

Finally, what explains the distribution of *Entada* in coastal sea areas and river banks? Water may play a key role for dispersal as well as for breaking of dormancy of big, heavy *Entada* seeds. The presence of aquatic micro-organisms and the lytic enzymes leached from them would soften the testa.

Despite the extensive spread of *Entada* genet in an alien environment, we are hesitant in attributing this as 'success', since ecologically 'success' is a measure of reproductive efficiency, namely the number of individual genets or ramets per unit area and density of liana growth[26]. Success of introduced *Entada* can only be assessed if it becomes naturalized by production of new genets or ramets.

Conclusion

A solitary *Entada* genet introduced in a research campus has provided an opportunity to observe new morphological features in a giant liana (Table 1), raising questions and ideas on the ecology of the lianas and the biomechanics of lianoid forms (Table 2). Some of the lead questions that have arisen from its regular observations are: (1) How did the liana construct the self-supporting trunk? (2) How does the liana sense availability of support tree from distance? (3) How do the aerial, cable-like stolons navigate precisely for infiltrating into the tree canopy? (4) How does the liana apply force to pull down a support (bamboo)? (5) What mechanisms liana uses to perceive and avoid an inadequate support in its trajectory? (6) How might have the liana growth habit evolved? (7) What is the lifespan of liana? (The general belief being that lianas have a long life-span). (8) Does *Entada* require a living tree for support?

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INTEGRATED WETLANDS ECOSYSTEM: SUSTAINABLE MODEL TO MITIGATE WATER CRISIS IN BANGALORE

Integrated wetlands system consists of sewage treatment plant, constructed wetlands (with location specific macrophytes), algal pond integrated with a lake. This model is working satisfactorily at Jakkur. The sewage treatment plant removes contaminants ~ 76 % COD (380 mg/l – 88 mg/l); ~78 % BOD (220-47 mg/l); and mineralises organic nutrients (NO_3-N, PO_4^{3-}-P to inorganic constituents. Integration of the conventional treatment system with wetlands [consisting of reed bed (with typha etc.) and algal pond] would help in the complete removal of nutrients in the cost effective way. Four to five days of residence time helps in the removal of pathogen apart from nutrients. However, this requires regular maintenance through harvesting macrophytes and algae (from algal ponds). Harvested algae would have energy value, which could be used for biofuel production. The combined activity of algae and macrophytes helps in the removal of ~45% COD, ~66 % BOD, ~33 % NO_3-N and ~40 % PO_4^{3}-P. Jakkur lake acts as the final level of treatment that removes ~32 % COD, ~23% BOD, ~ 0.3 % NO_3-N and ~34 % PO_4^{3}-P. The lake water with a nominal effort of sunlight exposure and filtration would provide potable water. Replication of this model in Bangalore would help in meeting the water demand and also helps in recharging of groundwater sources without any contamination.

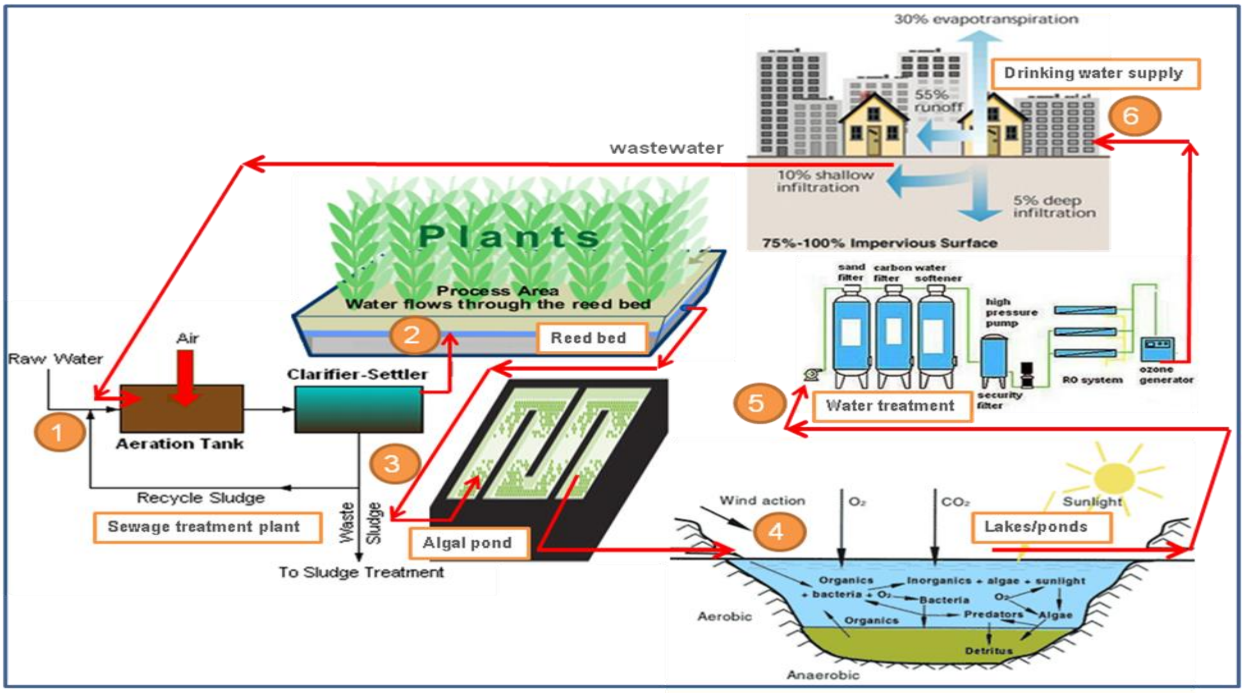

Figure 1: Integrated wetlands system for managing water and wastewater

Ramachandra T.V., Durga Madhab Mahapatra, Sudarshan P. Bhat, Asulabha K.S., Sincy Varghese, Bharath H. Aithal, 2014. Integrated Wetlands Ecosystem: Sustainable Model to Mitigate Water Crisis in Bangalore, ENVIS Technical Report 76, Environmental Information System, CES, Indian Institute of Science, Bangalore 560012

Functional aspects of the integrated wetlands systems are:

- Sewage Treatment Plant (STP): The purpose of sewage treatment is to remove contaminants (Carbon and solids) from sewage to produce an environmentally safe water. The treatment based on physical, chemical, and biological processes include three stages – primary, secondary and tertiary. Primary treatment entails holding the sewage temporarily in a settling basin to separate solids and floatables. The settled and floating materials are filtered before discharging the remaining liquid for secondary treatment to remove dissolved and suspended biological matter. STP's effluents were still nutrient rich requiring further treatment (for nutrient removal) and stabilization for further water utilities in the vicinity.

- Integration with wetlands [consisting of reed (typha etc.) beds and algal pond] would help in the complete removal of nutrients in the cost effective way. A nominal residence time (~5 days) would help in the removal of pathogen apart from nutrients. However, this requires regular maintenance of harvesting macrophytes and algae (from algal ponds). Harvested algae would have energy value, which could be used for biofuel production. The wetland systems helps in the removal of ~77 % COD, ~90% BOD, ~33% NO_3-N and ~75% PO_4^{3}-P (Figure 2).

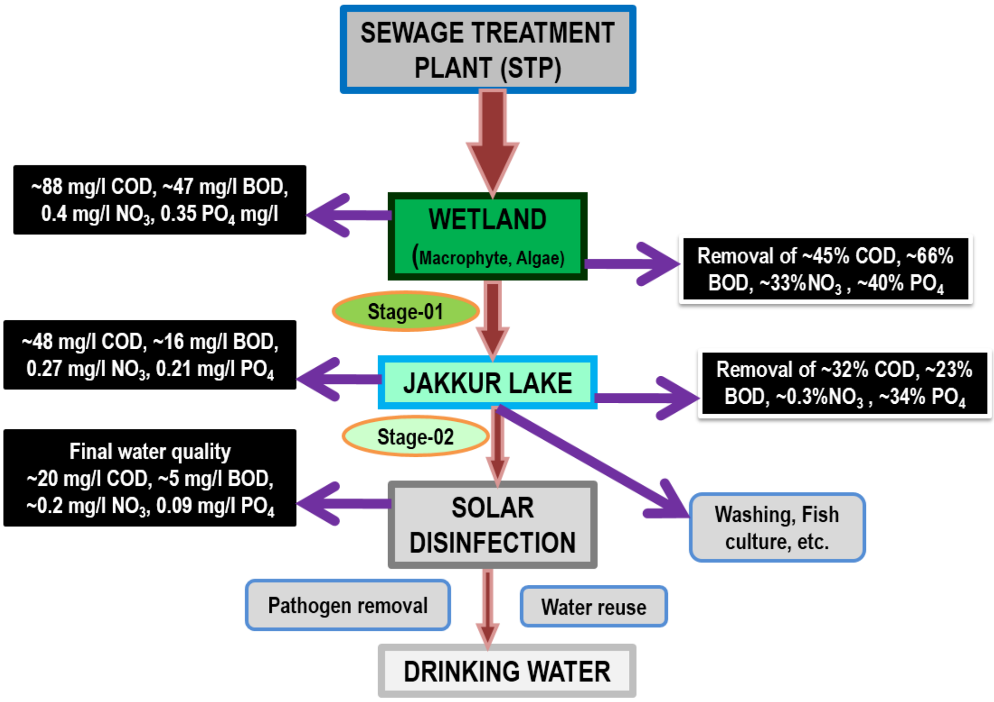

Figure 2: Level of treatment at various stages of integrated wetlands system

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Pilot scale experiment in the laboratory has revealed nutrient removal of algae are 86%, 90%, 89%, 70% and 76% for TOC, TN, Amm.-N, TP and OP respectively (Figure 11) and lipid content varied from 18-28.5 % of dry algal biomass. Biomass productivity is of ~122 mg/l/d and lipid productivity of ~32 mg/l/d. Gas chromatography and mass spectrometry (GC-MS) analysis of the fatty acid methyl esters (FAME) showed a higher content of desirable fatty acids (biofuel properties) with major contributions from saturates such as palmitic acid [C16:0; ~40%], stearic acid [C18:0; ~34%] followed by unsaturates as oleic acid [C18:1(9); ~10%] and linoleic acid [C18:2(9,12); ~5%]. The decomposition of algal biomass and reactor residues with calorific exothermic heat content of 123.4 J/g provides the scope for further energy derivation (Mahapatra et al., 2014). Water that comes out of the wetlands is portable with minimal efforts for pathogen removal via solar disinfection.

Our earlier experiments have shown the vital role of wetlands in recharging the groundwater resources, evident from the decline of groundwater table to 200-300 m from 30 to 50 m with the removal of wetlands. This means, Jakkur lake system is helping in recharging the groundwater sources. There need to be regulation on the exploitation of groundwater in Bangalore. Over exploitation of groundwater through borewells by commercial private agencies would harm the sustainability, depriving the local residents in the vicinity who are dependent on borewells in the absence of piped water supply from the government agency.

Measures required to mitigate water crisis in burgeoning Bangalore are:

1. Rainwater harvesting at decentralized levels through wetlands (lakes) is the most efficient and cost effective mechanism to address the water crisis in the region than technically infeasible, ecologically unsound and economically unviable river diversion or inter linking of river schemes being proposed by vested interests in various parts of the country.
2. Rejuvenation, restoration of existing lakes. This is necessary to decontaminate water bodies due to the unabated inflow of effluents and sewage.
3. Removal of deposited silt would enhance the storage capacity as well as bioremediation capability of lakes.
4. Integrated wetlands ecosystem (consisting of reed bed (typha, etc.), algal pond) with lake helps in the treatment of water entering the lake through bioremediation. Replicating Jakkur wetland ecosystem would help in the treatment of water and reuse. This also has an added advantage of maintaining groundwater quality in the vicinity.

Studies have shown that groundwater sources in the vicinity of sewage fed lakes are contaminated, evident from the nutrient enrichment, presence of coliform, etc.

5. Sustainable management of integrated wetlands ecosystem includes
    i). Letting only treated sewage to wetlands.
    ii). Maintaining at-least 33% vegetation cover in the lake catchment. This is necessary to ensure sufficient infiltration of rainwater to ensure water in the lake throughout the year.
    iii). Ban on number of borewells (or extraction of groundwater) in the lake catchment and command area
    iv). Restriction on overexploitation of groundwater in the lake catchment to ensure sustained water availability to the local residents
    v). Regular harvesting of macrophytes
    vi). Mechanism to harvest algae at regular interval and manufacture of biofuel and other beneficial biochemical products. These would enhance the employment opportunity in the region.
    vii). Provision of appropriate infrastructure for washer men who depend on the lake for livelihood through washing clothes.
    viii). Restriction on the introduction of exotic species of fish by commercial vendors
    ix). Permission to scientific fish culturing through strict regulations (on fish species introduction, type of nets, frequency of harvesting, restrictions during breeding season and locations)