J. Hortl. Sci.
Vol. 12(2) : 150-170, 2017

Original Research Paper

Integrating technological solutions to identify the potential locations for rainwater harvesting interventions in ICAR-IIHR farm at Hesaraghatta, Bengaluru.

A. Bhanu[1] and Suresh Ramaswwamyreddy[2]
[1] ICAR-Indian Institute of Horticultural Research, Hesaraghatta, Bengaluru
[2]Department of Civil Engineering,
BMS College of Engineering, Basavanagudi, Bengaluru.
*E-mail: bhanua@iihr.res.in

ABSTRACT

Water constitutes the prime requirement for existence and sustenance of all life forms. It is also the most vital component for enabling economic and social development. The quantum of rainfall and surface water availability have remained constant leading to over-exploitation of ground water, declining water table levels and deterioration of water quality.

ICAR-Indian Institute of Horticultural Research, Hesaraghatta, Bengaluru is wholly dependent on rains and borewell water for irrigation of experimental plots and laboratory needs apart from demand from other utilities and residential colony. There is water shortage because of reduced output from borewells, change in rainfall pattern, and, the dried up Aivarakhandapura lake. This resource scarcity has to be balanced critically with increasing water demand due to enhancement of cultivated land, more experimental activities, construction of new buildings and additional environment controlled polyhouses/ greenhouses. Devising practical solutions for management of scarce water resource is a big challenge.

This paper focuses on Water Conservation and Water Balance in farm area of ICAR - IIHR (in Arkavathy basin near Hesaraghatta) with morphological and hydro-geological analyses to understand the in-situ percolation / infiltration and runoff characteristics taking into account the topographical features of the area. The study also covers the application of Penman-Monteith equation standardized by the Food and Agricultural Organization (FAO56-PM) simultaneously with crop coefficient approach (single crop coefficient) for estimation of values of reference evapotranspiration (ETo) and crop evapotranspiration under standard conditions (ETc).

A series of systematic, logical and scientific steps are adopted to arrive at validated conclusions. This paper presents the data collected from various sources and tests which are compiled and collated using advanced computer applications like AutoCAD, Arc GIS, MS Excel and Adobe Photoshop. The results obtained from these applications are used to analyze and arrive at potential locations for engineering interventions in the farm area for effective and efficient harvesting of rainwater leading to conservation and ground water recharge.

Key words: rainwater harvesting, evapotranspiration, hydrogeomorphometric, infiltration, runoff, groundwater recharge, Aivarakhandapura watershed, Thornthwaite

INTRODUCTION

ICAR-IIHR was established on 5th September 1967 at ICAR Headquarters, New Delhi and was subsequently shifted to Hesaraghatta, Bangalore on 1st February 1968. A Fruit Research Station started by the Imperial Council of Agricultural Research was functioning here since 1938 and was converted in due course into National Hortorium. Initially, 24.7ha of land under National Hortorium was transferred to IIHR and later on the Government of Karnataka transferred 238ha of additional land **(Figure 1).**

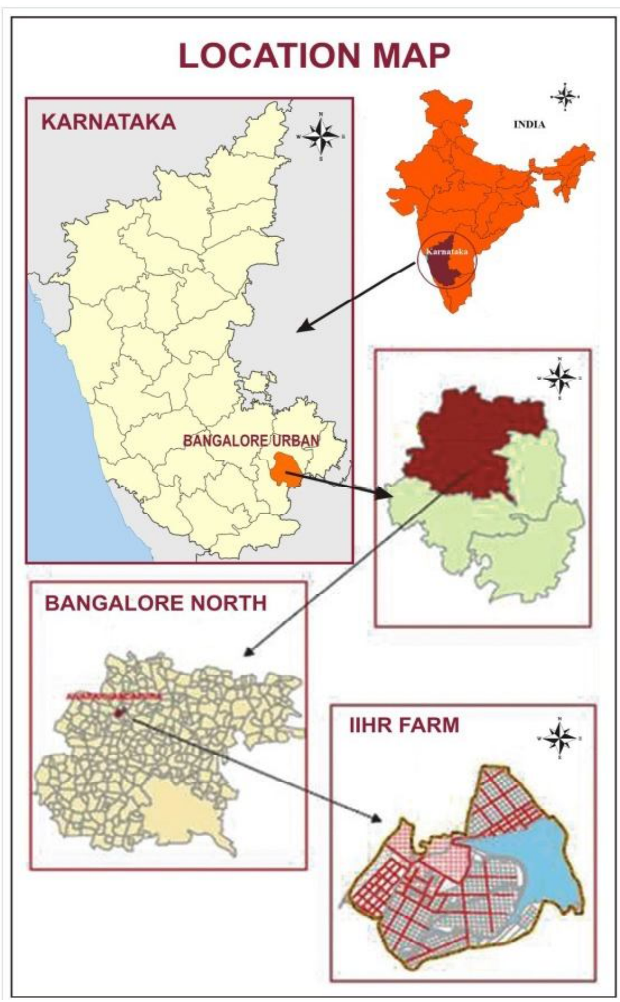

Fig. 1. Location Map

ICAR-IIHR Campus is geographically located between 13° 7' 34" to 13° 8' 40" N latitude and 77° 29' 9" to 77° 30' 8.5" E longitude. Google image of ICAR-IIHR campus is shown in **Figure 2.**

The 135 acre Aivarakhandapura Lake is a part of the Aivarakhandapura mini-watershed in Bangalore North Taluk of Bangalore Urban district.

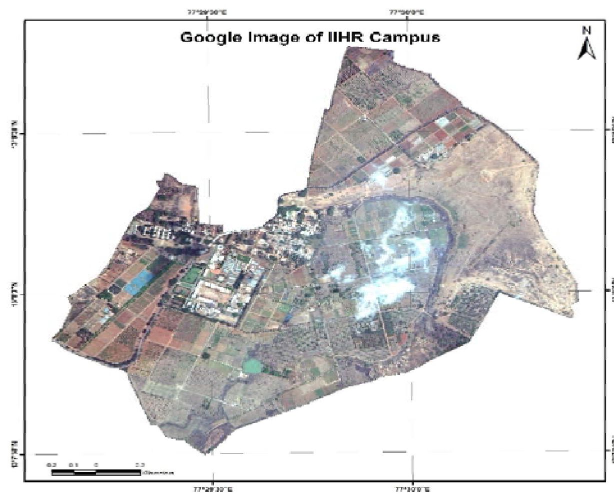

Fig. 2. Google image of ICAR-IIHR

LOCATION & GEOGRAPHICAL DETAILS

The present study is based on various parameters which are derived from Survey Of India (SOI) topomaps 57 G/8 and 57 G/12 **(Figure 3),** Karnataka State Remote Sensing Application Centre

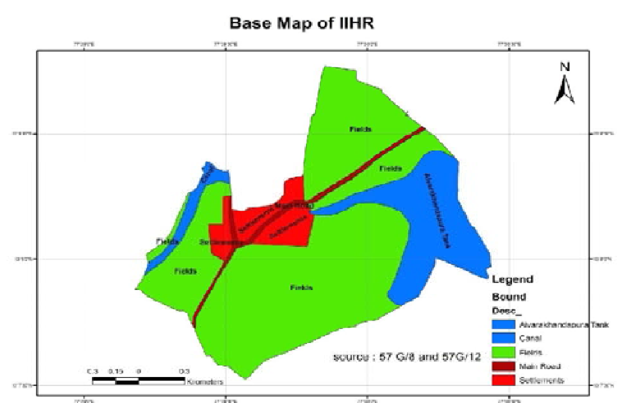

Fig. 3. Base Map of ICAR-IIHR

(KSRSAC) data, Rainfall Data from Indian Institute of Horticultural Research (IIHR), Google Earth Satellite Imagery and other collateral data.

The Aivarakhandapura mini watershed lies geographically between 77° 28' 53" E and 77° 33' 52" E longitude and 13°10'52" N and 13° 6' 24" N latitude. It covers an area of 33.145 Sq. km and shows the relief around 83 m (Highest being 949.2 m above MSL and lowest being 866.2 m above MSL). The watershed has length and width of 7.24 km and 6.24 km respectively. The SOI topomap of Aivarakhandapura watershed is shown in **Figure 4.** The Base Map of Aivarakhandapura watershed is shown in **Figure 5.**

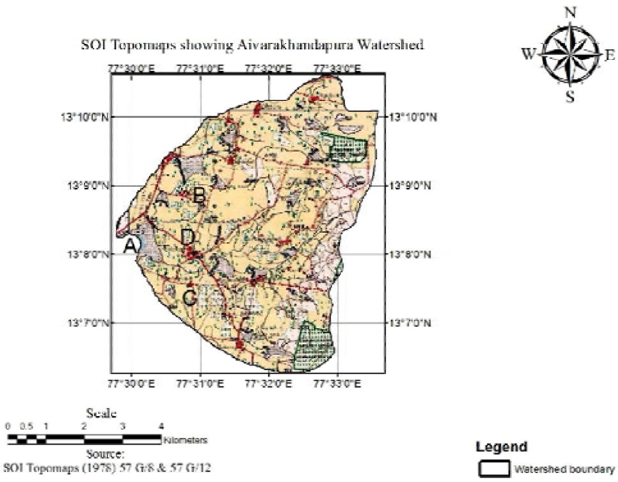

Fig. 4. SOI Topomap of Aivarakhandapura watershed

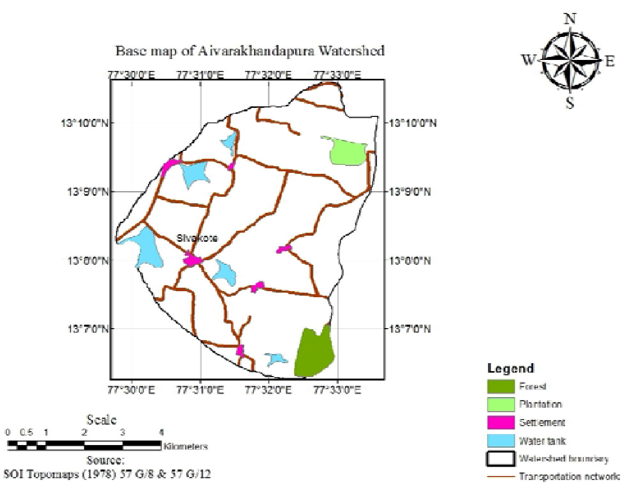

Fig. 5. Base map of Aivarakhandapura watershed

Physiography

Physiographically the area falls in the southern *maidan* region, which is characterized by undulating landscape with rather broad based valleys. The land forms are considered ancient and have undergone an extensive pediplanation, leading to the present landscape. The highest relief is formed at 949.2 m above mean sea level and lowest relief is obtained at 866.2 m above MSL. The slope of the land is from northeast to southwest. The overall relief for the watershed is calculated to be 83 m.

Geology

The study area consists one of the oldest rock formations of archean age. Peninsular gneiss covers a large area of the catchment. The important major rock types are granitic gneiss and banded gneiss. The granites are medium to coarse grained, prophyrites and equi-granular in texture and are mostly grey granite. These granites are bouldery at the surface and fresh / massive at depths. The presence of granite is displayed with rugged topography and as mounds (Subhash Chandra et al., 2012).

Natural Vegetation

Important natural vegetation found in the area is Casurina (*Casurina equisetifolia*), Tamarind (*Tamarindus indica*), Jack (*Artocarpus heterophillus*), Ashoka tree (Saraca indica), Eucalyptus (*Eucalyptus citradora*), Neem (*Azadirachta indica*) and Pongamia (*Pongamia pinnata*). Other surface plants, bushes and shrubs apart from grass and other small weeds also exist on ground. Lantana and *Parthenium hysterophorus* are most commonly seen.

Climate

The climate of the district is classed as seasonally dry tropical savanna climate of four main seasons. The cold weather dry season from December to February, the hot weather season begins in March with low humidity, April and May are the months of considerable thunder storm activity. The southwest monsoon season from June to September is a moist, cloudy & rainy period. The northeast monsoon season from October to November is also a moist and rainy period. December and January are generally the coolest months with the mean maximum temperature of 25°C and mean minimum of 15°C. Temperature increases gradually by March and April being the hottest month with the mean daily maximum temperature at 35°C and the mean daily minimum at 24°C. With the onset of monsoon early in June, there is appreciable drop in temperature. The mean daily maximum humidity of 85% and mean daily minimum humidity of 48% is recorded. Bangalore usually gets about 900mm of annual precipitation.

Architecture of study

The methodology/architecture of the study conducted in ICAR-IIHR is shown in **Figure 6.**

Drainage Pattern

The drainage pattern of the area reflects the soil and geology. The watershed flows in the general N-S direction and joins Arkavati river. The drainage

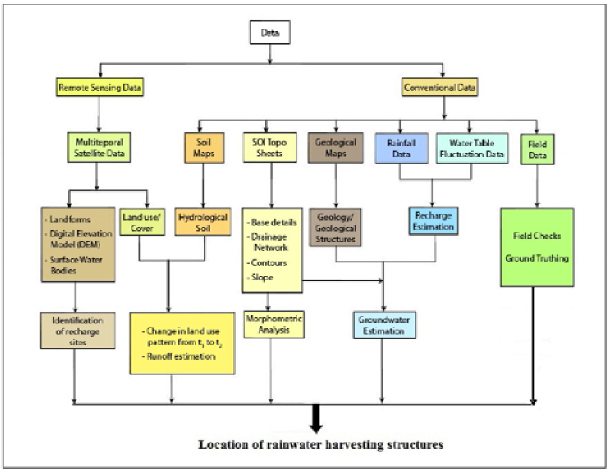

Fig. 6. Project Flow Chart

pattern is characterized by a single main stream joined by a number of tributaries and is only dendritic at the lower stream order **(Figure 7).** Dendritic pattern characterizes the semi-perviousness in the soil nature.

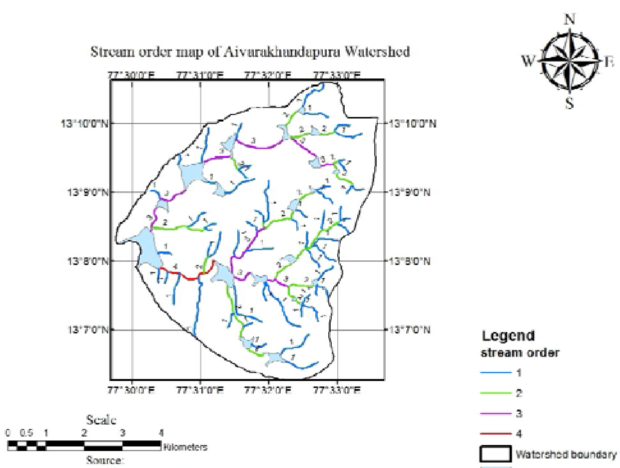

Fig. 7. Stream order map of Aivarakhandapura mini-watershed

Land use

The vegetation in the watershed is characterized by agricultural activity. Main crops during Kharif season are Ragi (Finger millet), pulses and oil seeds whereas paddy is grown in command areas of tank. As a result of increased irrigation by borewells, cropping pattern also changed and irrigated crops such as mulberry, sugarcane and cash crops have replaced the traditional crops. Later, the plantations replaced the cash crops and the gradual change in the terms of urbanization has converted the agricultural plantations into Scrub lands. Presently, the scrub lands are being converted into Settlements. The Government has also allotted land to ISRO, DRDO and TIFR for their new campuses close to ICAR-IIHR.

Land use – land cover pattern time series details for the Aivarakhandapura mini-watershed (Manasa,2011) are shown in **Figures 8, 9, 10, 11, 12** corresponding to respective years and the percentage area of Land Use / Land Cover for those years is also given in **Tables 1, 2, 3, 4, 5** below.

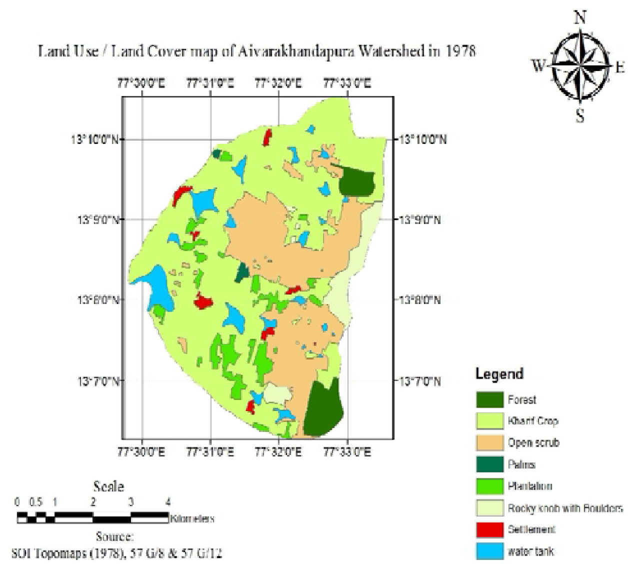

Fig. 8. LU-LC map of Aivarakhandapura mini-watershed for 1978

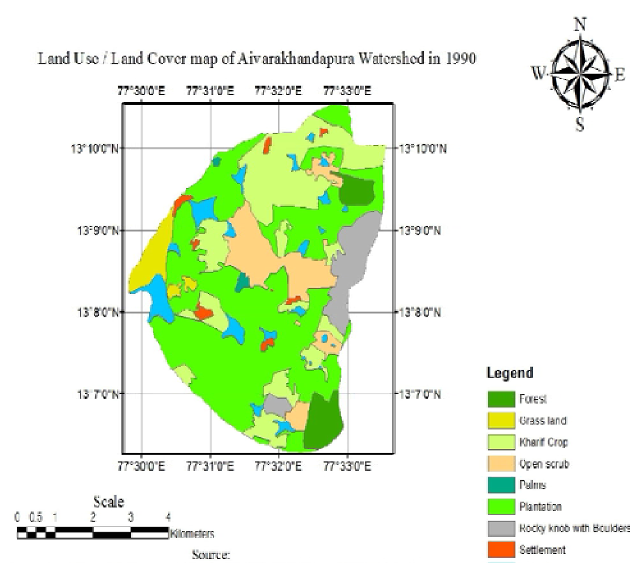

Fig. 9. LU-LC map of Aivarakhandapura mini-watershed for 1990

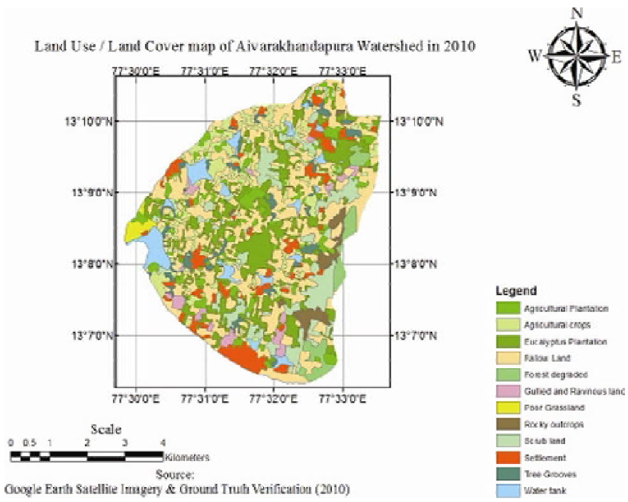

Fig. 10. LU-LC map of Aivarakhandapura mini-watershed for 2002

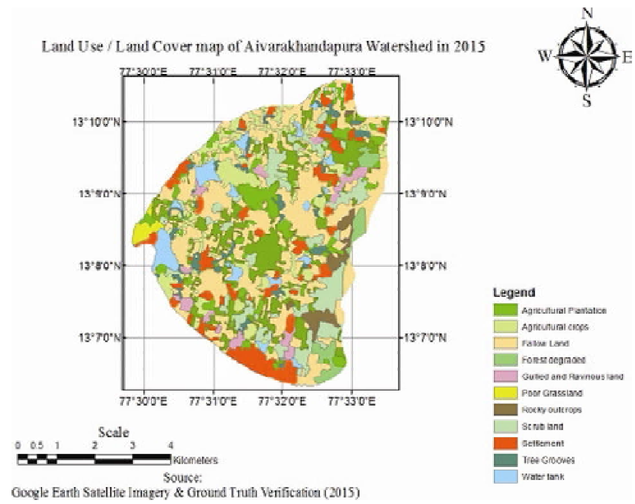

Fig. 11. LU-LC map of Aivarakhandapura mini-watershed for 2010

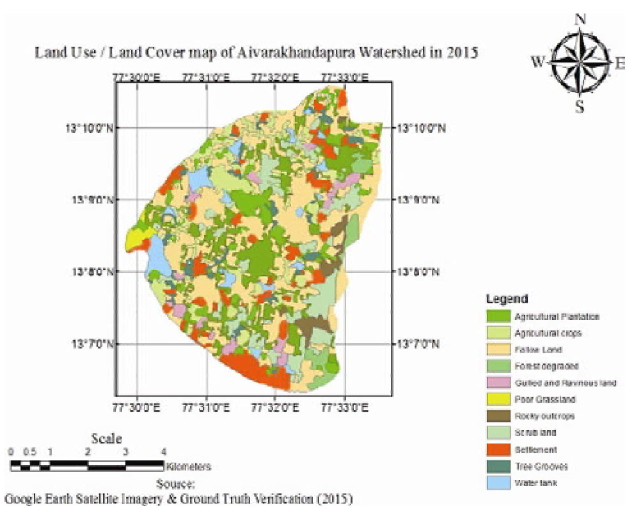

Fig. 12. LU-LC map of Aivarakhandapura mini-watershed for 2015

Table 2. Percentage area of each Land Use / Land Cover of the year 1990

Sl. No.	LU/LC Type	Area (sq. km)	% Area
1	Forest	0.980	2.95
2	Grass land	1.116	3.36
3	Kharif Crop	7.042	21.19
4	Open scrub	4.843	14.57
5	Plantain	14.01	41.54
6	Rocky outcrops	2.405	7.24
7	Settlement	0.970	3.2
8	Water tank	1.707	5.14
	Total	33.145	100.00

Table 1. Percentage area of each Land Use / Land Cover of the year 1978

Sl. No.	LU/LC Type	Area (sq. km)	% Area
1	Forest	0.980	3.12
2	Kharif crop	17.019	54.21
3	Open scrub	7.011	22.33
4	Plantation	2.000	6.37
5	Rocky knob	2.546	9.01
6	Settlement	0.689	2.19
7	water tank	1.150	3.66
	Total	33.145	100.00

Table 3. Percentage area of each Land Use / Land Cover of the year 2002

Sl. No.	LU/LC Type	Area (sq. km)	% Area
1	Agril. Plantation	12.983	36.21
2	Dense Grass land	1.166	3.52
3	Fallow land	0.087	0.26
4	Forest	1.420	4.29
5	Gullied / Ravenous Land	0.151	0.45
6	Kharif + Rabi (Double Crop)	0.052	0.16
7	Kharif crop	12.321	41.25
8	Lake / Tanks	2.214	6.68
9	Land with scrub	0.536	1.62
10	Scrub Forest	0.088	0.26
11	Village	1.53	4.65
	Total	33.145	100.00

Table 4. Percentage area of each Land Use / Land Cover type of the year 2010

Sl. No.	LU/LC Type	Area (sq. km)	% Area
1	Agril. Plantation	7.937	23.94
2	Dense Grassland	0.179	0.54
3	Fallow land	12.342	37.22
4	Forest degraded	1.294	3.90
5	Gullied and Ravenous Land	0.763	2.30
6	Kharif Crops	2.218	6.69
7	Water tanks	1.539	4.64
8	Rocky outcrops	0.736	2.22
9	Scrub land	2.832	8.54
10	Settlement	2.041	6.16
11	Tree Grooves	1.269	3.83
	TOTAL	33.145	100.00

Table 5. Percentage area of each Land Use / Land Cover of the year 2015

Sl. No.	LU/LC Type	Area (sq. km)	% Area
1	Crops	1.300	3.92
2	Fallow land	14.500	44.75
3	Forest degraded	1.230	3.71
4	Gullied and Ravenous Land	1.503	4.53
5	Plantation	6.000	18.09
6	Poor Grassland	0.160	0.48
7	Scrub land	2.800	8.44
8	Settlement	3.46	8.17
9	Tree Grooves	1.268	3.82
10	Water tank	1.380	4.16
	TOTAL	33.145	100.00

Soils

The soils in the catchment represent one of the oldest soils in the world as seen from organic carbon dating and also the Archean rocks. The soils in the watershed are deep red loams. They are derived from igneous rocks, principally granitic gneisses. The soils represent the running slopes, plains and undulating uplands with gently lowlands. The red soils are characterized by the light texture of sandy clay loam and clay loam, weak granular structure, porous, sticky and plastic, non gravelly and subsoil with argillaceous clay. The Soil Map of Aivarakhandapura watershed is shown in **Figure 13.**

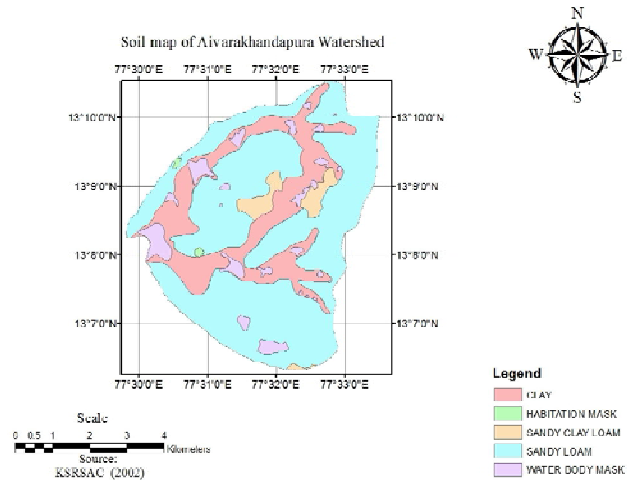

Fig. 13. Soil map of Aivarakhandapura watershed

Hydrogeomorphometry

Morphometric Analysis **is** done to understand the quantitative physical characteristics of Aivarakhandapura mini-watershed (Manasa,2011). The inferences drawn from the morphometric analysis are useful for water resource management and development. The knowledge of basin drainage characteristics is an important prerequisite to evaluate the basin hydrology. The amount of water reaching a system is dependent on morphometry, total precipitation, loses due to evapotranspiration by soils and vegetation. The quantitative morphometric parameters throw light on the lithology and structural control of the basin, relative runoff, recharge, erosion aspects and stage of development of the basin itself. The geomorphology and slopes of Aivarakhandapura watershed are shown in **Figure 14**. The different morphometric parameters of Aivarakhandapura watershed are given in **Table 6.**

Morphometric analyses

- The morphometric analyses of Aivarakhandapura mini-watershed results suggest that the watershed has a total relief of 83 m. The relief aspects show that the watershed has enough slope for runoff to occur from the source to the mouth of watershed.
- The value of R_b (3.03) in the present case indicates that watershed has suffered less structural

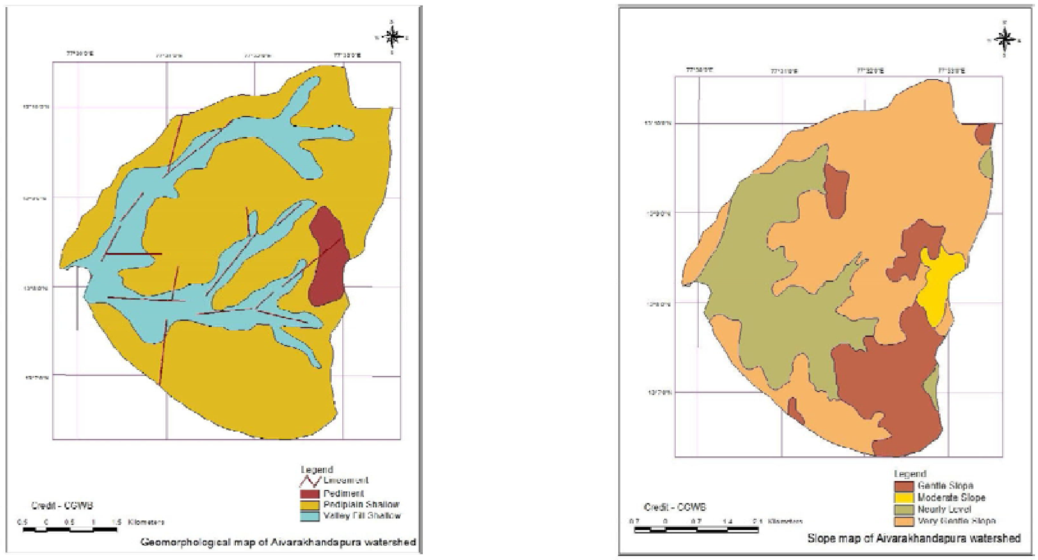

Fig. 14. Geomorphology and Slopes map of Aivarakhandapura mini-watershed

Table 6. Different morphometric parameters of Aivarakhandapura watershed

Sl No	Watershed Parameters	Units	Values
1	Watershed Area	Sq.km	33.145
2	Perimeter of the Watershed	km	24.277
3	Watershed Stream Highest Order	No.	4
4	Maximum Length of watershed	km	7.24
5	Maximum width of Watershed	km	6.24
6	Cumulative Stream Segments		89
7	Cumulative Stream Length	km	76.28
8	Length of overland flow	km	0.22
9	Drainage Density	km/Sq.km	2.30
10	Constant of Channel Maintenance	Sq.km/km	0.43
11	Stream Frequency	No/Sq.km	2.68
12	Bifurcation Ratio		3.03
13	Length Ratio		1.50
14	Form Factor		0.86
15	Shape Factor		1.58
16	Circularity Ratio		0.84
17	Elongation Ratio		0.89
18	Compactness Coefficient	1.19	
19	Total Watershed Relief	m	83
20	Relief Ratio		0.0115
21	Relative Relief	m/m	0.00345
22	Ruggedness Number	0.19	

disturbance and the watershed may be regarded as the circular one.

- Drainage density reflects land use and affects the infiltration and the watershed response time between the precipitation and discharge. For the Aivarakhandapura watershed, the drainage density is evaluated to be 2.30 km/sq.km which indicates that the area is coarser in nature and that the area has highly resistant or highly permeable sub-soil material.
- The length of overland flow 0.22 suggests that surface runoff will reach the streams faster. In contrast the watershed exhibits impermeable subsurface material, which is evident from the presence of narrow stream course.
- The circularity ratio for the watershed is 0.84, which indicates mature nature of topography. Its low, medium and high values area correlated with youth, mature and old stage of cycle of tributary watershed of the region.
- The elongation ratio is 0.89, which indicates that the watershed is circular.
- The stream frequency obtained for the study area is 2.68 no./sq.km. So it is classified under the class of low drainage density, leading to higher bifurcation ratio.

The satellite image (CARTOSAT+LISS IV image – March, 2010) of ICAR-IIHR Campus is shown in **Figure 15** below:

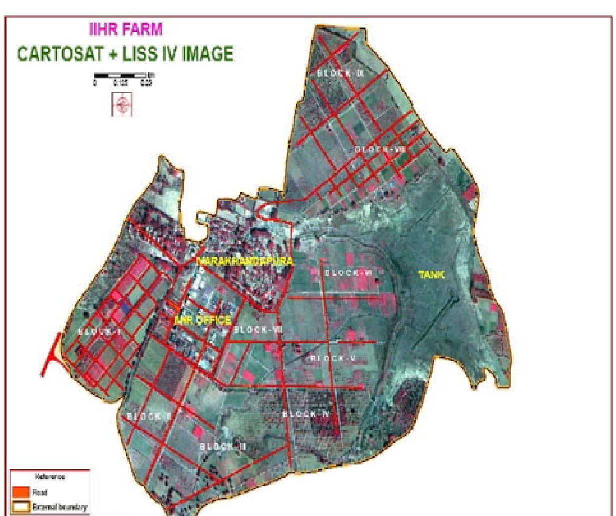

Fig. 15. Satellite image of ICAR-IIHR campus

The total station survey (2012) map of ICAR-IIHR Campus is shown in **Figure 16** below.

Fig. 16. Total station survey map ICAR-IIHR Campus

The Digital Elevation Map of ICAR-IIHR Campus derived from Google Satellite image is shown in **Figure 17.** The contour map of ICAR-IIHR

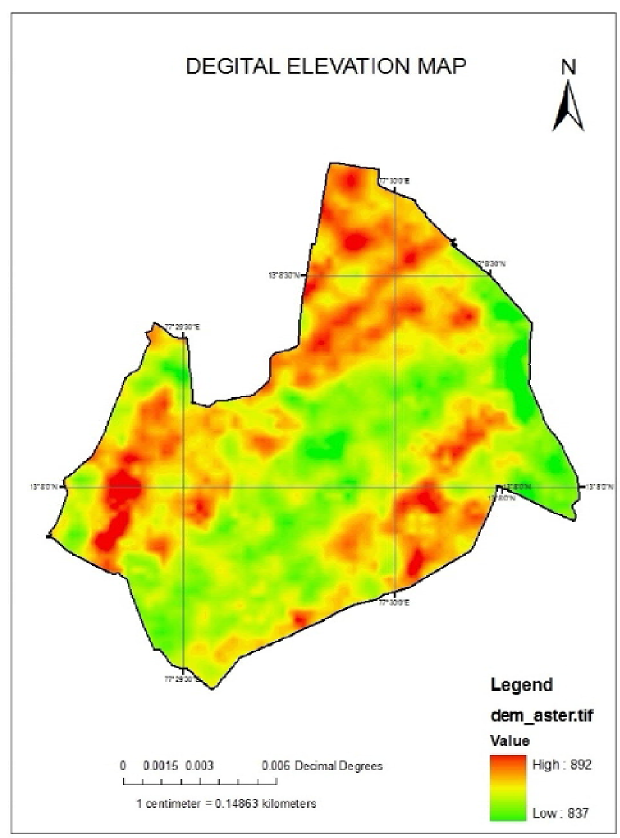

Fig. 17. DEM of ICAR-IIHR

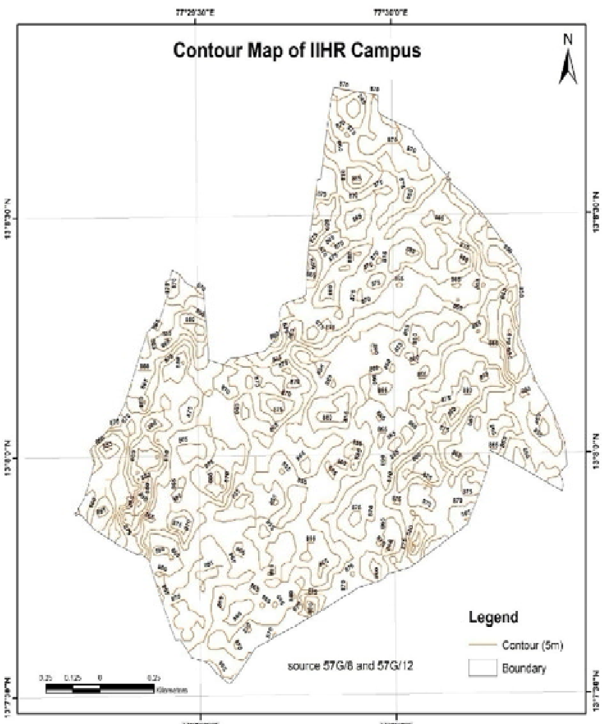

Fig. 18. Contour map of ICAR-IIHR

Campus plotted from SOI Topomaps is shown in **Figure 18.**

Soils

The soils are characterized by light texture of sandy clay loam and clay loam, weak granular structure, porous, sticky and plastic, non-gravelly and subsoil with argillaceous clay. The soils are moderate to well drained with infiltration rates ranging from 0 to 7.6mm/hr as reported in the Soils of IIHR (1965) and NBSS&LUP (1976 and 2013) (IIHR-NBSSLUP Soil Inventory REPORT, 2013).

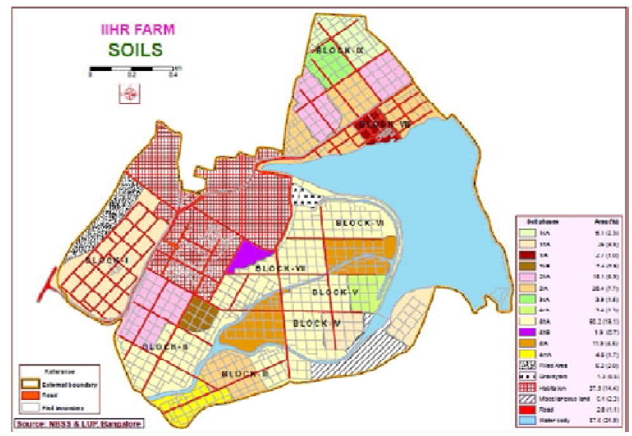

Fig. 19. Soil Profile of ICAR – IIHR Campus, Hesaraghatta, Bengaluru

The soil profile map of ICAR-IIHR is shown in **Figure 19.**

Table 7. Percentage Area of each land use / land cover type in the year 2013

Sl. No.	Total Area (hectares)	LU/LC Type	Area (hectares)	% Area
1		Agricultural Plantation	100.98	38.44
2		Built up Area	14.01	5.33
3	262.7	Open Area	79.58	30.29
4		Settlement	13.28	5.06
5		Water Bodies	54.85	20.88
Total			**262.7**	**100.00**

The Land use / Land cover map of ICAR-IIHR Campus for the year 2013 is shown in **Figure 20** and the corresponding details are given in **Table 7.**

EVAPOTRANSPIRATION

Estimation of evapotranspiration(Namrata Angadi, 2012) is one of the major hydrological components and it is very important for determining crop water requirement, scheduling irrigation at a regional level. Evapotranspiration rate is normally expressed in millimeters (mm) per unit time, representing the amount of water lost from a cropped surface in units of water depth. The time unit can be an hour, day, decade, month or even an entire growing period or year. The evapotranspiration rate is expressed in units of MJ m^2 day^{-1} is represented by λET, the latent heat flux.

FAO Penman-Monteith Method

In 1948, Penman combined the energy balance with the mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatological records of sunshine, temperature, humidity and wind speed. The FAO Penman-Monteith method is recommended as the sole ET_o method for determining reference evapotranspiration.

FAO Penman-Monteith Equation

The FAO Penman-Monteith equation is a close, simple representation of the physical and physiological factors governing the evapotranspiration process. By using the FAO Penman- Monteith definition for ET_o, one may calculate crop coefficients at research sites by relating the measured crop evapotranspiration (ET_c) with the calculated ET_o, i.e., $K_c = ET_c / ET_o$. The equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed.

The FAO Penman-Monteith method to estimate ET_o can be given as:

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where
- ET_o reference evapotranspiration [mm day^{-1}]
- R_n net radiation at the crop surface [MJ m^{-2} day^{-1}]
- G soil heat flux density [MJ m^{-2} day^{-1}]
- T mean daily air temperature at 2 m height [°C]
- u_2 wind speed at 2 m height [m s^{-1}]
- e_s saturation vapour pressure [kPa]
- e_a actual vapour pressure [kPa]
- e_s-e_a saturation vapour pressure deficit [kPa]
- Δ slope vapour pressure curve [kPa °C^{-1}]
- γ psychrometric constant [kPa °C^{-1}]

The daily climatic data at ICAR-IIHR Campus obtained from IIHR Weather Station are given in **Table 8.**

Table 8. Daily climatic data at ICAR - IIHR Campus

Month	Mean Max. temp (°C)	Mean Min. temp (°C)	Mean u_2 (ms^{-1})	Mean RH_{max} (%)	Mean RH_{min} (%)	n (hr day^{-1})
January	27.8	12.7	1.3	90	41.2	9.1
February	30.5	13.8	1.3	87	39.1	8.9
March	32.9	16.4	1.4	84.5	33.03	8.9
April	32.6	20.2	1.2	89.4	38.9	7.3
May	32.1	19.9	1.4	89.7	40.3	7.8
June	28.4	19.5	2.5	93.5	48.4	6.1
July	27.8	19.9	2.1	94	53.3	4.2
August	27.1	19.8	1.8	94.6	55.1	3.3
September	28.0	18.9	1.6	93.9	51.6	5.9
October	28.6	19.2	0.8	93.4	51.2	5.6
November	26.9	15.9	1.3	88.7	53.2	6.2
December	26.8	14.4	1.2	91.2	51.6	7.2

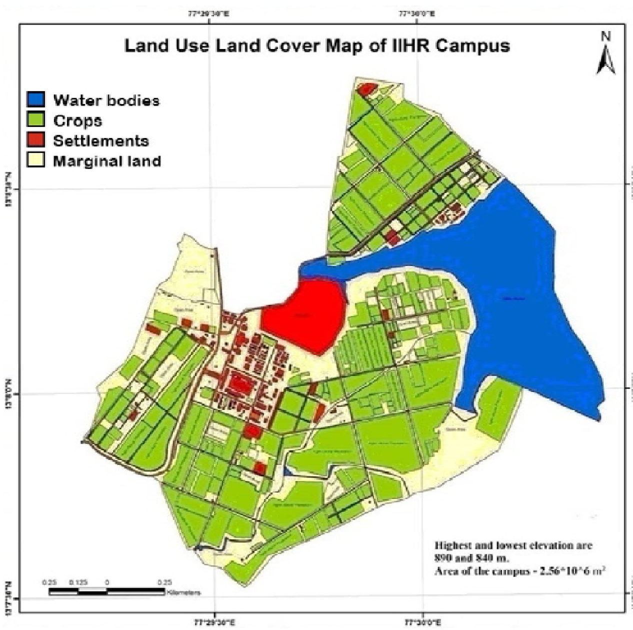

Fig. 20. Land use map of ICAR-IIHR

The average values of calculated parameters obtained from climatic data for ICAR-IIHR Campus is given in **Table 9.**

Table 9. Average values of the calculated parameters by FAO56-PM for ET_o estimates

Month	**Δ [kPa $^{\circ}C^{-1}$]**	**e_s [kPa]**	**e_a [kPa]**	**e_s-e_a [kPa] day^{-1}]**	**R_a [MJ m^{-2} day^{-1}]**	**R_s [MJ m^{-2} day^{-1}]**	**R_{so} [MJ m^{-2} day^{-1}]**	**R_{ns} [MJ m^{-2} day^{-1}]**	**R_{nl} [MJ m^{-2} day^{-1}]**	**R_n [MJ m^{-2}**
January	0.147	2.61	1.44	1.17	12.57	8.14	9.43	6.27	5.13	1.14
February	0.163	3.02	1.57	1.45	13.73	8.68	10.29	6.69	4.91	1.78
March	0.186	3.45	1.63	1.82	14.98	9.36	11.24	7.20	4.86	2.34
April	0.203	3.66	2.02	1.64	15.70	8.56	11.77	6.59	3.53	3.06
May	0.199	3.57	2.01	1.56	15.75	8.79	11.82	6.77	3.66	3.10
June	0.182	3.15	2.03	1.11	15.61	7.62	11.71	5.87	2.85	3.02
July	0.175	2.99	2.05	0.95	15.61	6.46	11.71	4.97	2.10	2.87
August	0.175	2.96	2.09	0.87	15.65	5.99	11.74	4.61	1.77	2.84
September	0.174	2.99	2.00	0.99	15.14	7.43	11.36	5.73	2.94	2.84
October	0.178	3.07	2.04	1.03	14.23	6.93	10.67	5.33	2.83	2.50
November	0.157	2.71	1.76	0.94	13.01	6.76	9.76	5.20	3.43	1.77
December	0.150	2.60	1.67	0.93	12.21	6.97	9.16	5.37	3.94	1.42

Monthly Reference Evapotranspiration (ET_o)

The monthly average value (Shivakumar et al.,2013) of ET_o is 56.1322 [mm month^{-1}], the maximum value is 74.939 [mm month^{-1}], and the minimum value is 38.373 [mm month^{-1}] as can be seen from **Table 10.**

Table 10. Calculated values of ET_o [mm month^{-1}]

Month	ET_0 (mm month^{-1})	Month	ET_0 (mm month^{-1})
January	46.599	July	63.363
February	53.597	August	55.878
March	72.453	September	54.162
April	64.954	October	39.534
May	69.106	November	40.623
June	74.939	December	38.373

The crop coefficient values for different crops grown in ICAR-IIHR is given in **Table 11.**

The calculated values of crop evapotranspiration and the corresponding volume of evapotranspiration of annual crops and perennial crops is given in **Table 12 and Table 13** respectively.

Table 11. Kc values for different Crops (Namrata Angadi, 2012) in ICAR - IIHR

ANNUALS

Crop/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Grapes	-	-	0.45	0.45	0.7	0.7	0.8	0.8	0.7	0.7	0.65	-
Onion	-	-	0.5	0.8	0.8	1.1	1.1	0.9	0.9	0.85	-	-
Green Peas	-	-	-	-	-	-	-	0.5	0.8	1.05	1.1	1.15
Tomato	-	-	-	-	-	-	-	0.5	0.8	1.15	0.9	0.6
Watermelon	-	-	-	-	-	-	-	-	-	-	0.5	0.8
Lemon	-	-	-	-	-	-	0.7	0.7	0.65	0.6	0.55	0.55
Cabbage	-	-	-	0.5	0.8	0.8	1.05	1.05	1.0	0.9	-	-
Cauliflower	-	-	-	1.05	1.05	1.05	1.05	0.95	0.95	-	-	-
Cucumber	-	-	-	-	-	-	0.6	1.0	0.75	-	-	-
Drumstick Plantation	-	-	0.6	0.65	0.7	0.75	0.8	0.8	-	-	-	-
Beans	-	-	-	-	-		0.5	0.5	1.05	1.05	0.9	0.9
Avocado	-	-	-	-	-	0.42	0.43	0.49	0.51	0.61	-	-
Chilli	-	-	-	-	-	0.75	0.8	0.8	0.7	0.6	-	-
Ridge gourd	-	0.55	0.6	-	-	-	-	-	-	-	-	-
Bitter gourd	-	-	0.6	0.65	-	-	-	-	-	-	-	-
Brinjal (Egg Plant)	-	-	-	-	-	0.75	0.8	-	-	-	-	-
Lady's finger	-	-	-	-	-	0.75	0.8	-	-	-	-	-
Gooseberry	-	-	0.4	0.4	0.65	0.85	0.85	0.8	0.75	0.75	-	-

PERENNIALS

Crop/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Banana	0.4	0.4	0.45	0.5	0.6	0.7	0.85	1.0	1.1	1.1	0.9	0.8
Guava	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Papaya	0.9	0.9	0.95	1.05	1.05	1.05	1.1	1.1	1.1	1.05	0.9	0.9
Pummelo	0.25	0.25	0.3	0.3	0.4	0.4	0.45	0.45	0.5	0.5	0.5	0.5
Black Plum	0.15	0.15	0.2	0.57	0.57	0.98	0.98	1.19	1.19	1.19	0.98	0.56
Trees	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
Passion Fruit	0.3	0.3	0.75	0.9	1.09	1.09	1.09	0.9	0.7	0.7	0.5	0.5
Custard Apple	0.2	0.2	0.4	0.5	0.5	0.7	0.7	0.6	0.6	0.6	0.4	0.4
Jackfruit	0.4	0.4	0.6	0.6	0.8	0.8	0.8	0.7	0.6	0.55	0.4	0.2
Fig Plantation	0.7	0.7	0.7	0.68	0.68	0.65	0.65	0.68	0.68	0.7	0.7	0.7
Litchi	0.4	0.4	0.9	1.2	1.2	0.85	0.85	0.4	0.4	0.4	0.4	0.4
Ornamental Plants	0.2	0.2	0.23	0.23	0.27	0.29	0.3	0.3	0.28	0.26	0.22	0.2
Chickoo (Sapota)	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Rose	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Mango	0.9	0.97	1.0	1.03	0.98	0.95	0.85	0.75	0.67	0.66	0.85	0.86
Pomegranate	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75

Table 12. Calculated values of ET_c of Annual Crops & Volume of ET of Annual Crops

ET_c of Annual Crops			Volume of ET of Annual Crops	
Crops	Time period	ETc (mm season-1)	Area (*1000m^2)	Volume ET (*10^3 m^3 season^{-1})
Avocado	June-Oct	137.84	6.41	0.88
Beans	July-Jan	229.10	19.1	4.38
Bitter gourd	Mar-Apr	85.69	1.83	0.16
Brinjal (Egg Plant)	June-July	106.89	4.78	0.51
Cabbage	Apr-Oct	362.66	0.72	0.26
Cauliflower	Apr-Sept	390.52	3.55	1.39
Chilli	June-Oct	213.23	7.54	1.61
Cucumber	July-Sept	134.52	1.93	0.26
Drumstick	Mar-Aug	285.66	0.42	0.12
Gooseberry	Mar-Oct	332.41	15.3	5.09
Grapes	Mar-Nov	350.05	26.7	9.35
Green Peas	Aug-Jan	201.59	1.97	0.40
Lady's finger	June-July	106.89	8.11	0.87
Lemon	July-Dec	185.84	1.15	0.21
Onion	Mar-Oct	428.25	7.51	3.22
Ridge gourd	Feb-Mar	72.95	0.55	0.04
Tomato	Aug-Dec	176.32	29.5	5.20
Watermelon	Nov-Feb	51.01	14.7	0.75
	TOTAL	3969.65	TOTAL	34.84

Table 13. Calculated values of ETc of Perennial Crops & Volume of ET of Perennial Crops

ET_c of Perennial Crops			Volume of ET of Perennial Crops	
Crops	**Time period**	**ETc (mm season^{-1})**	**Area (*1000m^2)**	**Volume ET (*10^3 m^3 season^{-1})**
Banana	Jan-Dec	479.14	12.2	5.85
Black Plum	Jan-Dec	480.76	1.01	0.49
Sapota/Chickoo	Jan-Dec	505.19	87.7	44.30
Custard Apple	Jan-Dec	334.20	35.1	11.73
Guava	Jan-Dec	505.19	55.5	28.04
Jackfruit	Jan-Dec	405.73	37.1	15.05
Litchi	Jan-Dec	475.14	1.92	0.91
Mango	Jan-Dec	597.88	384.5	229.88
Pummelo	Jan-Dec	263.89	4.26	1.12
Papaya	Jan-Dec	681.81	35.5	24.20
Passion Fruit	Jan-Dec	524.31	5.68	2.98
Fig Plantation	Jan-Dec	459.71	10.58	4.86
Ornamental Plants	Jan-Dec	169.86	73.4	12.47
Pomegranate	Jan-Dec	505.19	3.14	1.59
Rose	Jan-Dec	538.86	0.61	0.33
Trees	Jan-Dec	464.77	17.4	8.09
	TOTAL	7391.63		391.89

RAINFALL

Daily rainfall data for 30 years (1987 to 2016) were collected from the IIHR campus, Hesaraghatta, recorded in the IIHR Weather Station (RAINFALL DATA Source - ICAR-IIHR). The mean annual rainfall for 30 years was 875.86 mm but variation occurs from year to year. The maximum rainfall of 1365 mm has been recorded in 1988 and minimum annual rainfall of 472 mm in 1990. The graphical representation of the rainfall data is shown in **Fig. 21** below.

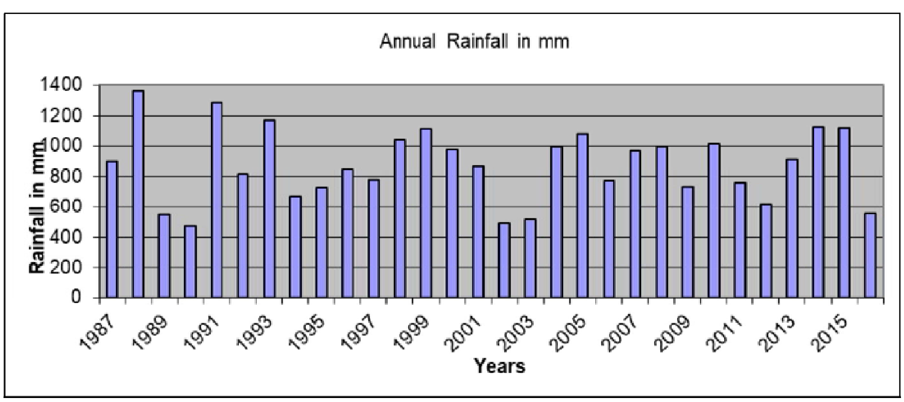

Fig. 21. Graph of annual rainfall in mm in ICAR-IIHR Farm for the year 1987 to 2016

As can be inferred from the **Table 14**, it is rare to see Heavy rainy days (8 days in past five years), Very heavy rainy days (zero in recent five years) and extremely heavy rainy days (1 day in past 30 years). Light rain days and Moderate rain days are more common and show a constant recurring trend.

Rainfall between 2.5 to 35.5mm per day is what can be expected more in the area.

RUNOFF

Runoff means the draining or flowing off of the precipitation from a catchment area through a surface channel. The precipitation volume is probably the single most important meteorological characteristic in estimating the volume of runoff. The soil type, land use and the hydrologic condition of the cover are the watershed factors that will have the most significant

Table 14. Intensity of rainfall as per IMD classification (for 5 years period)

Period	Classification	1987-91	1992-96	1997-2001	2002-06	2007-11	2012-16
0mm	No Rain day	1494	1471	1405	1450	1453	1529
0.1-2.4mm	Very light rain days	79	84	134	137	94	36
2.5-7.5mm	Light rain days	105	123	113	98	106	101
7.6-35.5mm	Moderate rain days	122	121	143	117	149	132
35.6-64.4mm	Rather heavy rain days	16	23	21	19	17	20
64.5-124.4mm	Heavy rain days	5	4	9	5	7	8
124.5-244.4mm	Very heavy rain days	5	1	1	0	0	0
>244.5mm	Extremely heavy rain days	0	0	0	0	0	1

impact in estimating the volume of runoff. The antecedent soil moisture (AMC) is also an important determinant.

In the present study, runoff is estimated using the Soil Conservation Services Curve Number (SCS-CN) method suggested by United States Department for Agriculture (USDA, 1972) which has found wide acceptability among hydrologists. In this model, runoff is determined as a function of current soil moisture content, static soil conditions, and management practices.

Curve Number is an index that represents the combination of hydrologic soil group and antecedent moisture conditions. Runoff estimation was done for the Aivarakhandapura mini-watershed using the SCS-CN method and the results [2] are given in **Table 15.**

Table 15. Annual rainfall and runoff (SCS – CN) in mm

Year	Annual Rainfall in mm	Annual Runoff in mm
LU/LC of 1978		
1987	899.3	190.26
1988	1365.4	461.88
1989	550	114.4
LU/LC of 1990		
1990	472.1	52.26
1991	1289.6	411.93
1992	817.5	108.16
1993	1174.8	443.13
1994	669.1	67.52
1995	729.5	105.06
1996	850	166.09
1997	780.6	141.46
1998	1042	252.61
1999	1118.9	229.01
2000	976.1	210.79
2001	867.9	170.78

Year	Annual Rainfall in mm	Annual Runoff in mm
LU/LC of 2002		
2002	491.4	100.29
2003	520.4	16.91
2004	995.96	217.87
2005	1078.6	297.37
2006	770.2	123.23
2007	972.3	197.04
2008	997.6	204.49
2009	733.2	49.45
LU/LC of 2010		
2010	1012.5	229.07
2011	761.4	103.9
2012	617.2	127.06
2013	914.7	192.39
2014	1125.8	274.55
LU/LC of 2015		
2015	1122.5	230.43
2016	559.2	94.19

Figures 22, 23 and 24 show the graphical details of Rainfall – Runoff relationship for the period 1987 to 2016.

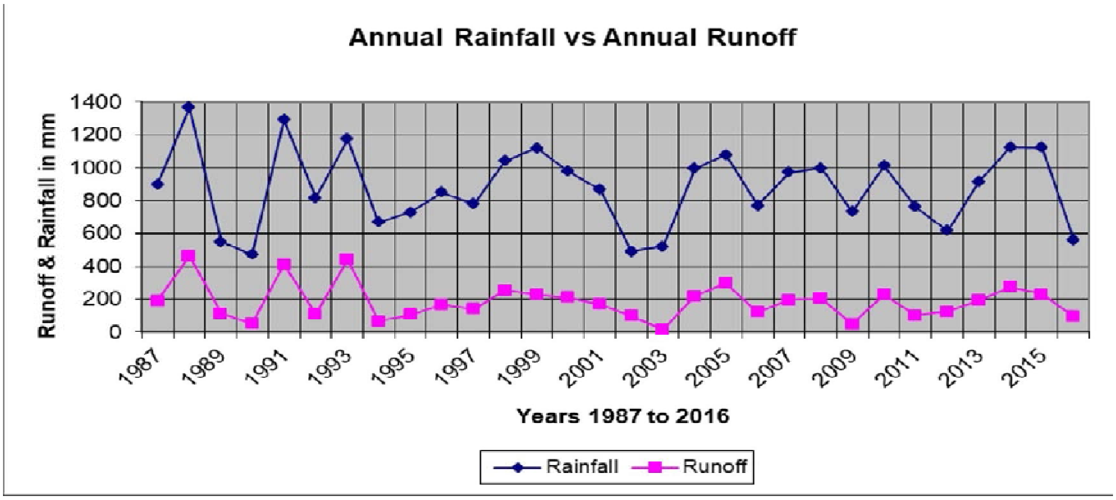

Fig. 22. Graph of annual runoff and rainfall in mm for 1987 to 2016

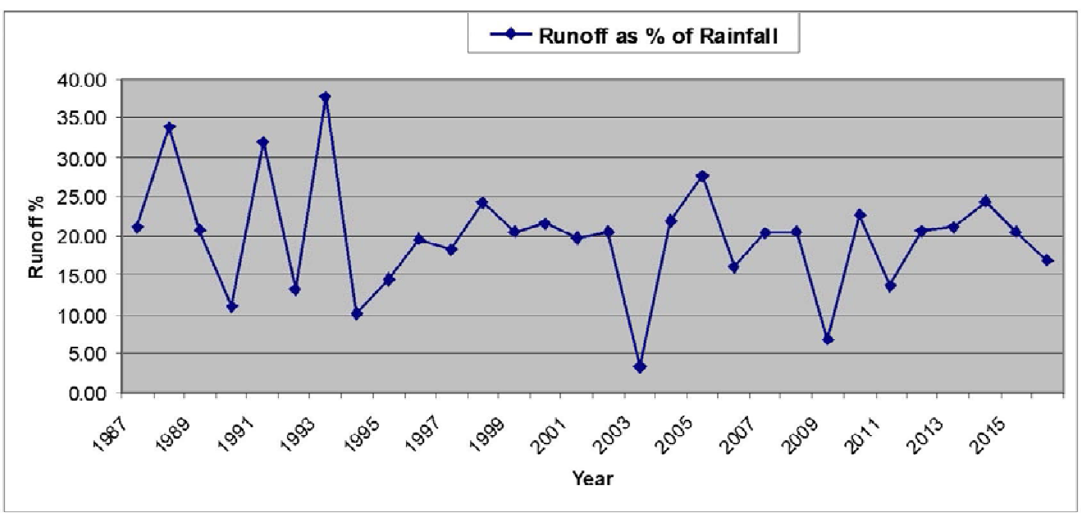

Fig. 23. Graph of annual runoff in mm for 1987 to 2016

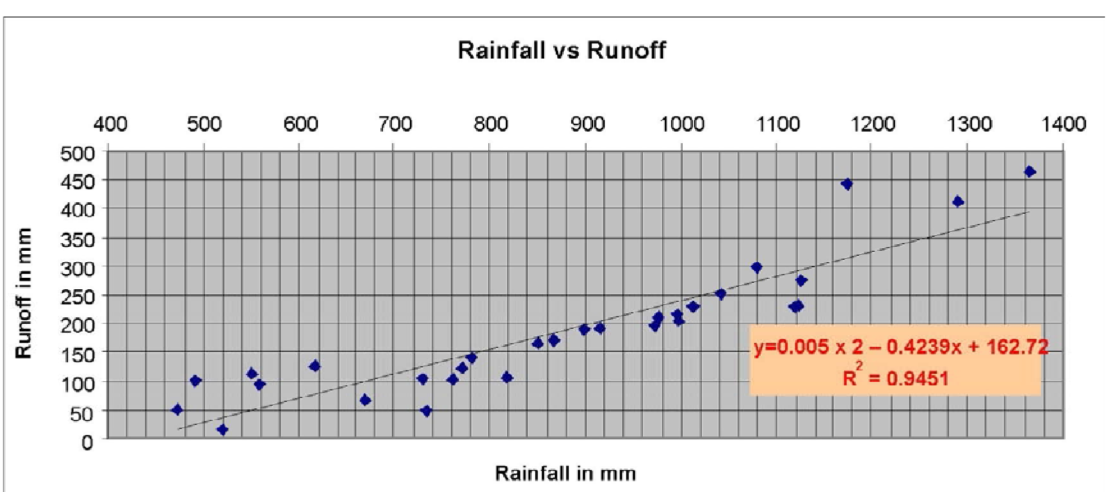

Fig. 24. Scatter plot of annual rainfall vs runoff in mm

THORNTHWAITE Model

This is a "monthly water-balance model" driven by a graphical user interface (GUI) developed by the U.S. Geological Survey, referred to as the Thornthwaite monthly water-balance program (McCabe and Markstrom, 2007). Computations of monthly water-balance components of the hydrologic cycle are made for a specified location. The program is a research tool, an assessment tool, and a tool for classroom instruction. Inputs to the model are mean monthly temperature (*T*, in degrees Celsius), monthly total precipitation (*P*, in millimeters), and the latitude (in decimal degrees) of the location of interest. The latitude of the location is used for the computation of day length, which is needed for the computation of potential evapotranspiration (*PET*).

The GUI permits the user to easily modify water-balance parameters and provide useful estimates of water-balance components for a specified location. **Figure 25** shows the computer screen image of Thornthwaite monthly balance model indicating the various input parameters.

In the present instance, the Thornthwaite modeling has been used to derive the runoff estimates for comparison and validation with the data obtained from SCS-CN method of calculations. It is seen from the graphs of SCS-CN method and Thornthwaite model that the results are similar in nature which validates the output from both methods.

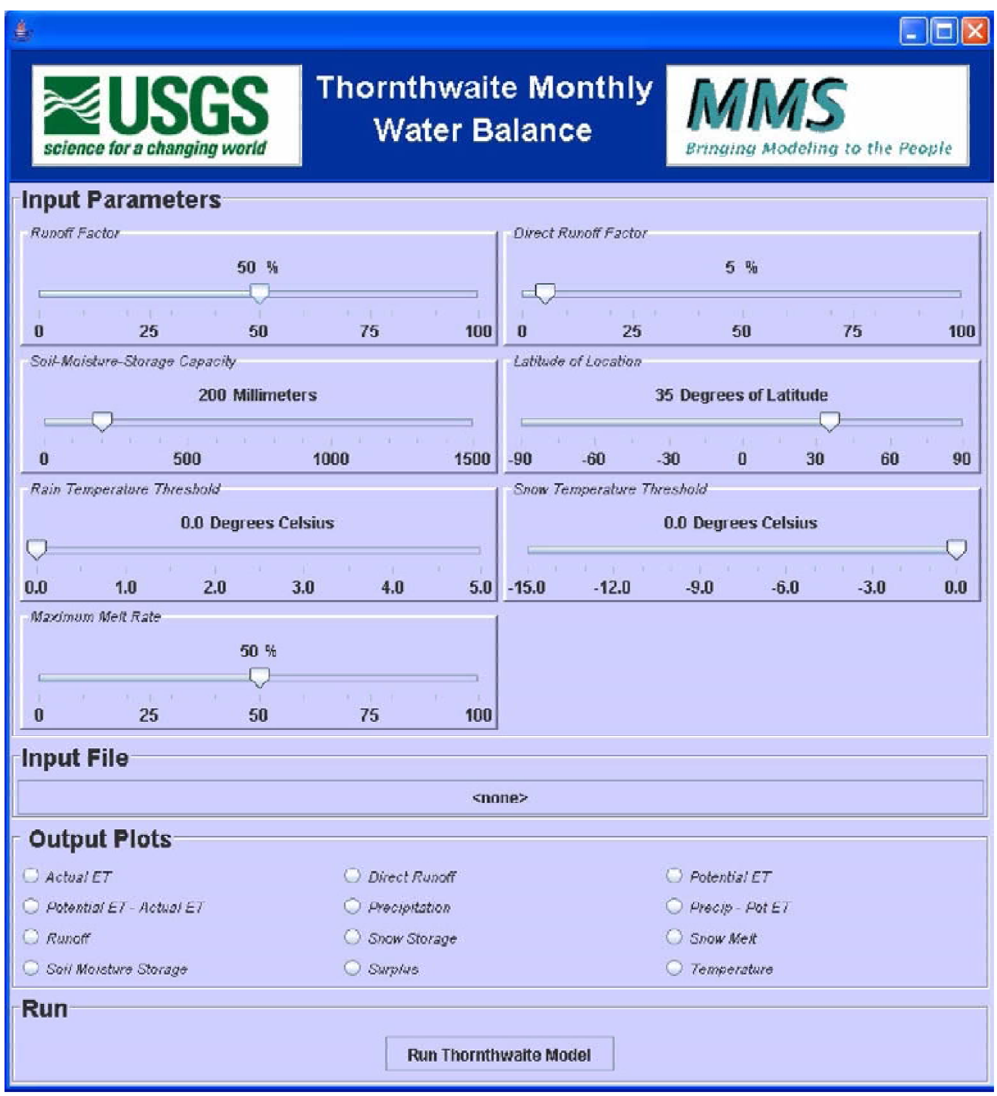

Fig. 25. Screen image of the water-balance model graphical user interface

Figures 26 and 27 give the graphical output from Thornthwaite analysis.

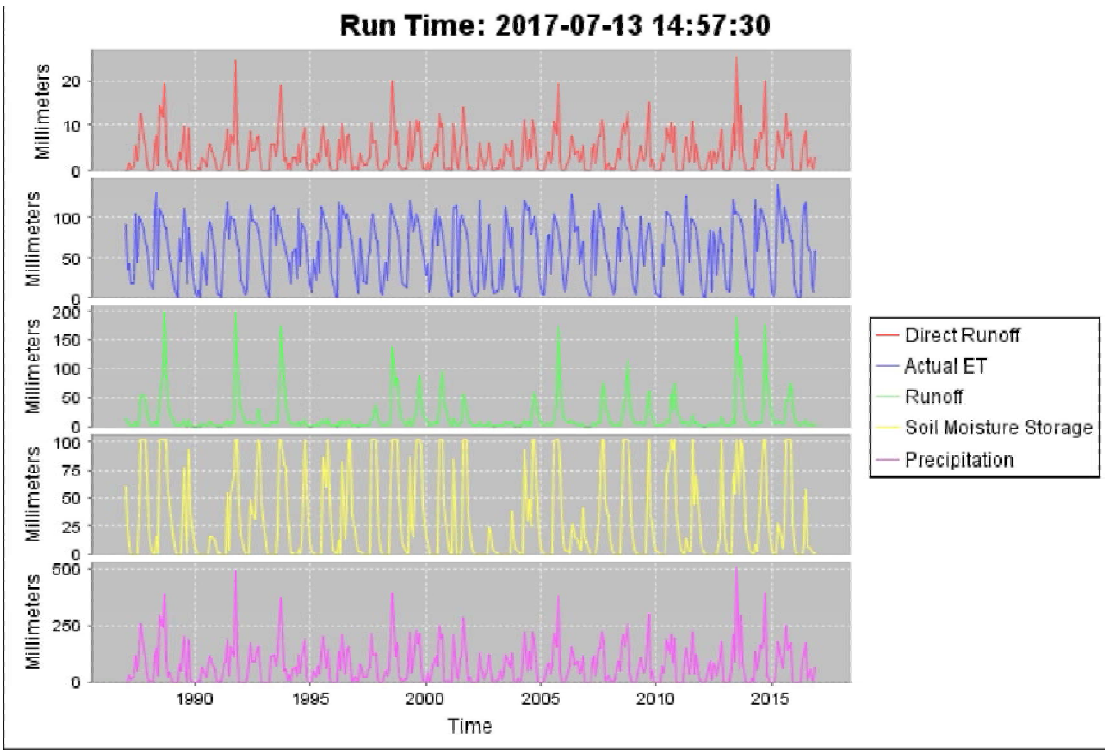

Fig. 26. Thornthwaite Model graphical output

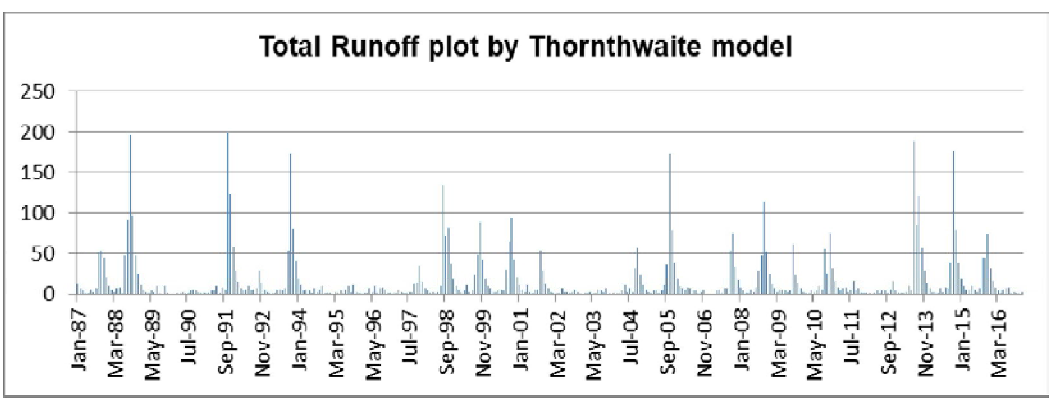

Fig. 27. Total annual sum of (in mm) graph by Thornthwaite Model

On comparison of the graphs plotted for values obtained from SCS – CN method and Thornthwaite model, and keeping in view the limitations of such comparison, it is seen that they are nearly similar, although Thornthwaite model returns lower values of runoff as has been reported by several researchers.

INFILTRATION

Infiltration studies were conducted in ICAR-IIHR by dividing the area in to 300X300 m grid and choosing the centre point of individual grid square. This provided an uniform distribution of test points over a wide area on an objective basis ruling out any scope for subjective or arbitrary selection of test points. The test points are also representative of the area covered. Total of 26 points were chosen for infiltration tests and located on ground using hand held GPS device as depicted in **Fig. 28** below. The infiltration tests were conducted in ICAR-IIHR campus during the months of March, April

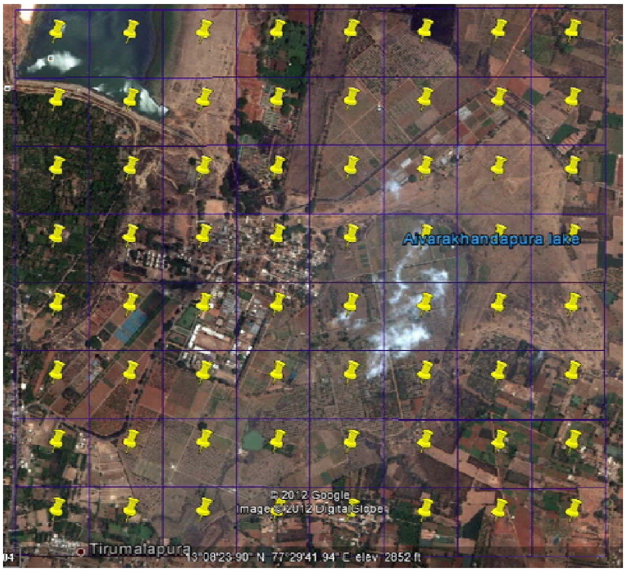

Fig. 28. Grid center points

and May for determining the infiltration rate by using the square infiltrometer (Ravindranath, 2012). The rate of infiltration of different 300x300m blocks is shown in **Fig. 29.**

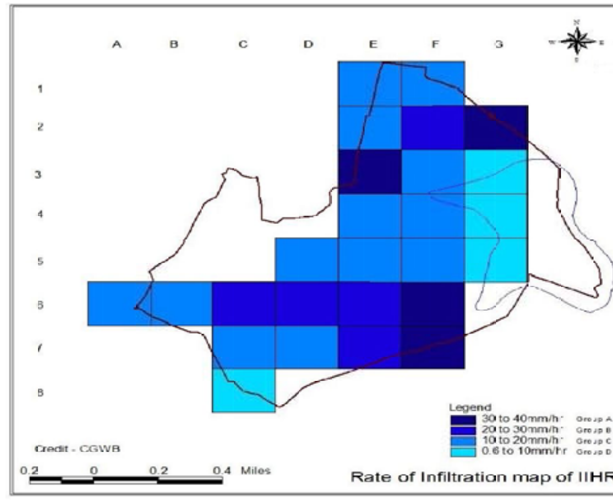

Fig. 29. Rate of infiltration map of ICAR-IIHR

The Rate of Infiltration data at different points in the grid with the lat-long coordinates and soil type is given in **Table 16.**

The hydrogeomorphological features of ICAR-IIHR Campus as derived from satellite image analyses is shown in **Fig.30, 31 and 32.**

Table 16. Rate of infiltration at different points in ICAR - IIHR

Sl. No.	Point	infiltration rate	Soil Type	infiltration rate range	Sl. No.	Point	infiltration rate	Soil Type	infiltration rate range
1	A6	12	C	10 to 20 mm/hr	14	E6	28	B	20 to 30 mm/hr
2	B6	16	C	10 to 20 mm/hr	15	E7	28	B	20 to 30 mm/hr
3	C6	30	B	20 to 30 mm/hr	16	F1	12	C	10 to 20 mm/hr
4	C7	20	C	10 to 20 mm/hr	17	F2	22	B	20 to 30 mm/hr
5	C8	8	D	0.6 to 10 mm/hr	18	F3	20	C	10 to 20 mm/hr
6	D5	12	C	10 to 20 mm/hr	19	F4	20	C	10 to 20 mm/hr
7	D6	30	B	20 to 30 mm/hr	20	F5	18	C	10 to 20 mm/hr
8	D7	10	C	10 to 20 mm/hr	21	F6	40	A	30 to 40 mm/hr
9	E1	18	C	10 to 20 mm/hr	22	F7	40	A	30 to 40 mm/hr
10	E2	20	C	10 to 20 mm/hr	23	G2	33	A	30 to 40 mm/hr
11	E3	40	A	30 to 40 mm/hr	24	G3	9	D	0.6 to 10 mm/hr
12	E4	12	C	10 to 20 mm/hr	25	G4	6	D	0.6 to 10 mm/hr
13	E5	20	C	10 to 20 mm/hr	26	G5	6	D	0.6 to 10 mm/hr

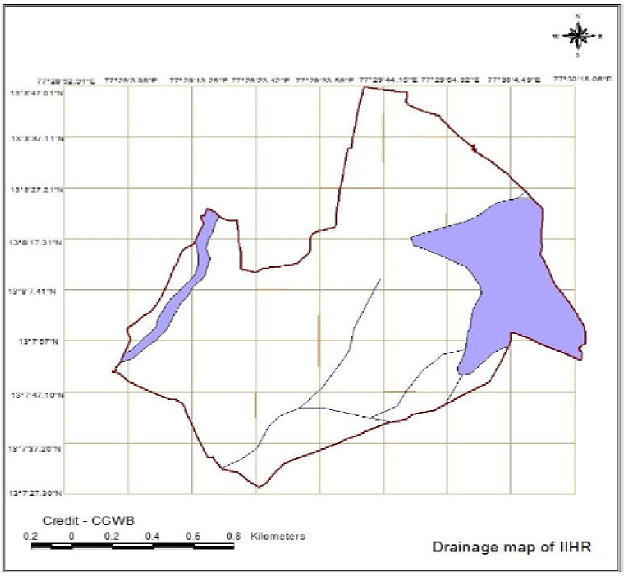

Fig. 30. ICAR-IIHR Drainage map of campus

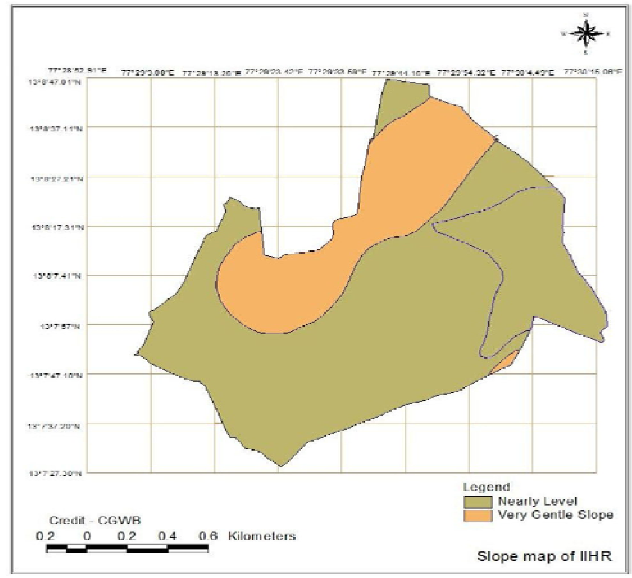

Fig. 31. ICAR-IIHR slope of campus

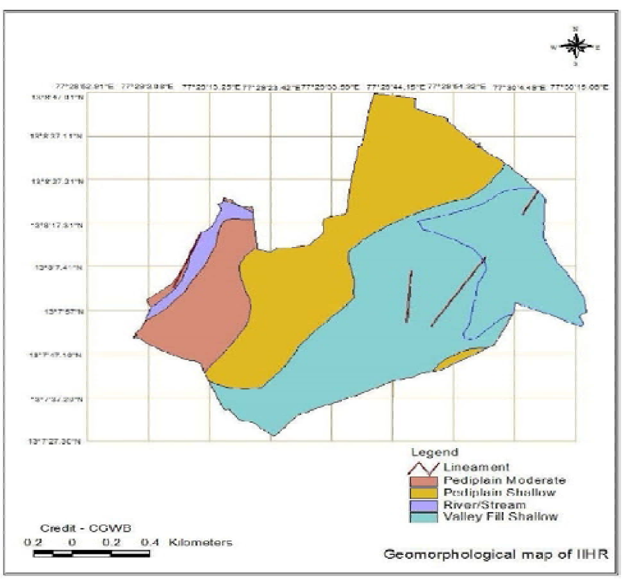

Fig. 32. ICAR-IIHR geomorphological map

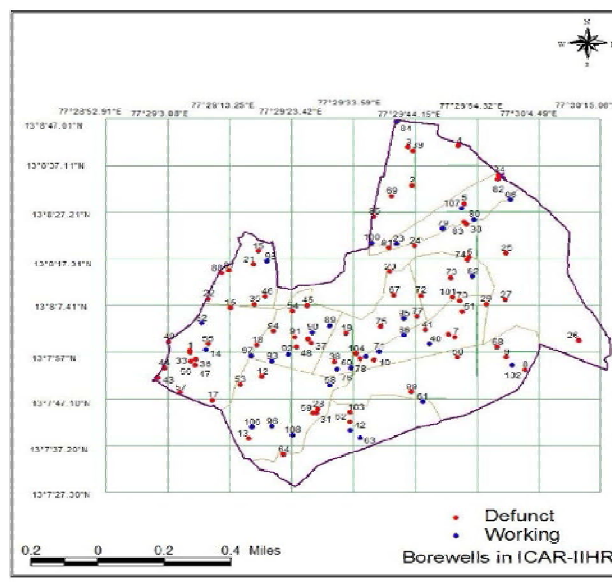

Fig. 33. Bore well inventory of ICAR-IIHR

BOREWELLS IN ICAR-IIHR

The water requirement for irrigation of experimental plots in addition to varied demands of laboratory and residential needs are met from groundwater resources and rainfall. The critical status of availability of water resources to meet the entire water demand for varied purposes brought about a situation to drill more number of borewells to increased depths.

There are in total 108 borewells in ICAR-IIHR Campus of which only 32 are yielding water and the other 76 are defunct. The depth of boreholes ranges from 200 feet (in Laboratory Campus – Bore well No.92) to 1282 feet (in Block 2 – Bore well No.108).

The blockwise details of borewells in ICAR-IIHR Campus are given in **Fig.33.**

CONCLUSIONS

The following findings were arrived at:

- The water demand has been estimated based on the evapotranspiration studies in ICAR-IIHR farm. It is estimated that the total volume of water [7] required to fulfill ET_c requirement of IIHR Campus is 426.6×10^3 m^3/year. This implies that an average of 35.5×10^3 m^3/month and 1168.83 m^3/day of water is required to fulfill ET_c requirement; whereas, the water required for fulfilling ET_c on daily basis varies from 365.80 m^3 to 2191.26 m^3.

- The Runoff estimation based on SCS-CN method has been compared and validated using the Thornthwaite Model.
- The Rainfall-Runoff correlation coefficient is defined by the equation

  (y=0.005x-0.4239x+162.72) based on SCS-CN method where 'y' represents Runoff in mm and x represents Rainfall in mm. The co-efficient of correlation R = 0.9451 (>0.80) meaning the equation predicted mathematically is accurate for the given x and y data.
- The proposed RWH structures could consist of Nallah Bunds, Contour Bunds, Contour Trenches, Ponds, Percolation Pits and Deep Bore Recharge Structures (Point Recharge Structures) depending on the slopes and drainage characteristics.
- The defunct borewells in the farm areas are also potential points for recharge of ground water.
- The RWH locations are to be identified based on a model / algorithm taking into account the slope and drainages, contours and elevations, soil profile, geological lineaments and the rate of infiltration map of ICAR-IIHR Campus.

REFERENCES

Subhash Chandra K.C and Hegde G.V, 2012, *Groundwater in hard rock terrain of eastern maidan tract of Karnataka: Is it a sustainable resource?* ; Proceedings of Workshop on "Water, Energy and Food Security", Dept. of Rural Development and Panchayat Raj, Govt. of Karnataka and Department of Civil Engineering, DSCE, Bengaluru, 2012, pp. 22 to 29

Manasa. M (09GAMC7003), 2011, *Estimation & Prediction of Runoff Based on Land Use / Land Cover Changes of Ivarakandapura Watershed*, M Tech Thesis – Bangalore University.

IIHR-NBSSLUP Soil Inventory REPORT 2013, ICAR-NBSS & LUP, Bangalore

Namrata Angadi (10GAMC7004), 2012, *Crop Evapotranspiration for Different Agricultural Plantations of IIHR Campus*, M Tech Thesis – Bangalore University.

Shivakumar J. Nyamathi and Namrata Angadi, 2013, *Estimation of Evapo-transpiration for different Seasonal Crops and Horticultural Plantations*, 3rd International Engineering Symposium - IES 2013. March 4-6th, 2013, Kumamoto University, Japan.

RAINFALL DATA Source - ICAR-IIHR Weather Station, Division of Plant Physiology and Bio chemistry, ICAR-IIHR, Hesaraghatta.

McCabe, G.J., and Markstrom, S.L., 2007, *A monthly water-balance model driven by a graphical user interface*: U.S. Geological Survey Open-File report 2007-1088, 6 p.

(http://water.usgs.gov/lookup/get?crresearch/mms/thorn)

Ravindranath (10GAMC7006), 2012, *Spatial Variation of Infiltration at IIHR CAMPUS*, M Tech Thesis – Bangalore University.

(MS Received 13 October 2017, Revised 06 November 2017, Accepted 25 December 2017)