WATER BALANCE STUDY OF KCAET CAMPUS FOR SUGGESTING SUITABLE WATER HARVESTING STRUCTURES

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PROJECT REPORT

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DECLARATION

We hereby declare that this project entitled "**Water balance study of KCAET campus for suggesting suitable water harvesting structures**" is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

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SYMBOLS AND ABBREVIATIONS

BD	-	Bulk density
cm	-	centimetre
CV	-	Coefficient of variation
ET	-	Evapotranspiration
et. al.	-	and others
FAO	-	Food and Agricultural Organization
gm	-	gram
ha	-	hectare
J kg^{-1}	-	joules per kilogram
kg/m^2	-	Kilogram per square meter
km^3	-	cubic kilometer
kPa/ °C	-	Kilo Pascal per degree centigrade
mm	-	millimeter
m^2	-	square meter
m^3	-	cubic meter
mham	-	million hectare meter
mm	-	millimeter
mmd^{-1}	-	millimeter per day
ms^{-1}	-	meter per second
OFR	-	On farm reservoir
PVC	-	Polyvinyl chloride
RF	-	Rainfall

RTWH	-	Roof top water harvesting
SD	-	Standard deviation
t ha^{-1}	-	tones per hectare
Wm^{-2}	-	Watts per square meter
WR	-	Water requirement

Chapter 1

INTRODUCTION

Water is the most precious natural resource. In many regions of the world, the pressure of economic development is producing a surface-water scarcity. Yet in most places, groundwater can be found within a relatively short distance below the ground surface. The pervasive and seemingly abundant supply of groundwater has led to its indiscriminate and sometimes excessive use. However, this use can have diverse and often wide ranging effects on the local and regional hydrology and ecology. To avoid depletion of ground water table, aquifer must be recharged equally. The storage of rain water on surface is a traditional technique. Use of structures like underground tanks, ponds, check dams, weirs etc. to recharge ground water is a new concept of rain water harvesting. Rain water can be collected overhead or stored on the soil surface or discharged in to the ground for direct use as well as supplemental use during non rainy season.

Precipitation is the natural recharging source for the surface water resources and it also maintain the hydrological cycle. Rivers are the major source of water in India. The utilizable annual surface water in rivers of the country is 690 km^3. The annual potential of natural groundwater recharge from rainfall in India is about 342.43 km^3, which is 8.56% of total annual rainfall of the country. Technically, more water can be mobilized by harnessing remote rivers, capturing floods, melting polar ice or desalinating sea water, but a steeply increased cost in terms of finance, energy and environment.

The total geographical area of Kerala is 38863 km^2 and the average rainfall is 300 cm. Kerala is wedged between the Lakshadweep Sea and the Western Ghats, lying between North Latitudes 8°18' and 12°48' and East Longitudes 74°52' and 77°22', Kerala experiences the humid equatorial tropic climate. Kerala owes its lushness to the monsoon. During the South West monsoon from June to September, water-saturated clouds from the vast Indian Ocean and the Arabian sea, hit the coast, and rain pours as if the sky has opened its floodgates. Heavy rain falls almost continuously every day for a week or two during June and July. This South West monsoon is associated with the calamitous floods that annually cause great loss of life in the Indian subcontinent, particularly in the flat lands in Bengal and the Indo-Gangetic plains.

From October to November, on the slopes of the Sahya Mountains, the North East monsoon provides the rainfall in Tamil Nadu in the east. Some clouds that get through the ghats on to the Western slopes create from nowhere sudden bursts of frightening electrical storms and thundershowers in the afternoons. This is a daily event. It pours for a few minutes and stops abruptly. Bright, hot, humid, sunshine pours out from the sky and the land is dry again.

On an average, the province receives between 330 and 506 cm of rain annually, most of it during the two monsoons. Kerala has been experiencing increasing incidents of drought in the recent past due to the weather anomalies and developmental pressures resulting from the changes in land use, traditional practices, and life style of the people. The increase in population and subsequent expansion in irrigated agriculture, and industrial growth necessitated the exploitation of more water resources. The changes in the land and water management practices affected the fresh water availability during summer months. Although the deviation in the annual rainfall received in Kerala, in any year from the long term average is very small, there is considerable variation in the rainfall availability during the different seasons. About 95 percent of annual rainfall is confined to a six-month monsoon period between June and November, leaving the remaining six months as practically dry.

Experts were confident that water scarcity could be a thing of the past in just five years if cheap and user-friendly methods of rainwater harvesting were employed extensively. They pointed out that because of the topographical peculiarities; the major amount of water that Kerala receives after a rain gets washed off into the sea within two days. The quantity of water that seeps down during the monsoon seasons is low and hence the water level in open wells is not sufficiently recharged.

The experts suggested that by adopting simple and cheap conservation methods, the surface runoff could be staggered and the quantity of rainwater seeping into the earth could be stepped up. The severity of water scarcity in summer could be warded off in this way. Some of the methods suggested to increase water retention were: digging pits in open spaces in the villages, terraced farming, building bunds of mud and stone and widening the coverage of vegetation. These methods would increase the soil's capacity for water absorption.

Rainwater harvesting is the accumulating and storing of rainwater for reuse before it reaches the aquifer. It has been used to provide drinking water, water for livestock, water for irrigation, as well as other typical uses. Rainwater collected from the roofs of houses and local institutions can make an important contribution to the availability of drinking water. It can supplement the subsoil water level and increase urban greenery. Water collected from the ground, sometimes from areas which are especially prepared for this purpose, is called Storm water harvesting. In some cases, rainwater may be the only available, or economical, water source. Rainwater harvesting systems can be simple to construct from inexpensive local materials, and are potentially successful in most habitable locations. Roof rainwater may not be potable and may require treatment before consumption. As rainwater rushes from your roof it may carry pollutants, such as mercury from coal burning buildings, or bird faeces. Although some rooftop materials may produce rainwater that would be harmful to human health as drinking water, it can be useful in flushing toilets, washing clothes, watering the garden and washing cars; these uses alone halve the amount of water used by a typical home. Household rainfall catchment systems are appropriate in areas with an average rainfall greater than 200 mm (7.9 in) per year, and no other accessible water sources (Skinner and Cotton, 1992). Overflow from rainwater harvesting tank systems can be used to refill aquifers in a process called groundwater recharge; though this is a related process, it must not be confused with rainwater harvesting.

There are several types of systems to harvest rainwater, ranging from very simple home systems to complex industrial systems. The rate at which water can be collected from either system is dependent on the plan area of the system, its efficiency, and the intensity of rainfall.

In hydrology, a water balance equation can be used to describe the flow of water in and out of a system. A water balance can be used to help manage water supply and predict where there may be water shortages. It is also used in irrigation, runoff assessment, flood control and pollution control. Further it is used in the design of subsurface drainage systems which may be horizontal (i.e. using pipes, tile drains or ditches) or vertical (drainage by wells). To estimate the drainage requirement, the use of a hydro geological water balance and a groundwater model may be instrumental.

The water balance is an accounting of the inputs and outputs of water. The water balance of a place, whether it is an agricultural field, watershed, or continent, can be determined by calculating the input, output, and storage changes of water at the Earth's surface. The major input of water is from precipitation and output is evapotranspiration.

The KCAET campus spreads over an area of 40.07 ha with 30.66 ha under agricultural use depending mainly on groundwater for its varied needs. It has been observed that during rains the surface water is wasted as runoff and the groundwater table is fast declining as years go by. The total water requirement of KCAET campus is 76100 m^3. The water is required for various purposes such as drinking, cooking, washing, bathing, sanitary and for irrigation purposes. Mainly these requirements are met by the water supply from wells present in the campus. There are 10 open wells, 5 tube wells and 6 ponds. All these structures are used for the household and irrigation requirements.

The present study was undertaken with the following objectives,

1. To assess the water demand, both agricultural and non-agricultural within KCAET campus.
2. To analyse the rainfall distribution and evaporation for rainwater harvesting prospects and water budgeting.
3. To suggest technically feasible and economically viable agricultural and non-agricultural rainwater harvesting systems.

Chapter 2

REVIEW OF LITERATURE

2.1 Roof water harvesting

In rooftop rain water harvesting systems, the rainwater is collected from roof of the buildings and diverted through delivery systems, like gutters, down pipes to filtration tanks and to storage tanks. The over flow of rainwater in storage tank can be diverted to abandoned dug well or well to recharge under- ground aquifer system. By implementing this technique, a large portion of rainfall, which generally goes waste, can be used for recharging wells so that the steep decline in water levels can be arrested by localized effects of communities.

Gould (1996) suggested the potential house hold rain water collection system for improving water supplies in rural Botswana. The possibilities for supplementing community supplies are demonstrated through pilot project using roof catchments and ferro- cement rainwater tank at rural schools and clinics. The paper also pointed the benefits of using surface runoff for livestock, tress and crops.

Murthy *et al.* (2000) worked out the total quantity of water that could be harvested from ARS Taluk office building at Gouribidanur, Karnataka. The roof area was about 900 m^2 and the total annual rainfall was 650 mm. The total quantity of water that could be harvested or recharged during a year was worked out to be 585 m^3. The water collected was made to flow into a recharge pit. The water from the roof was collected through drain pipes and made to pass through a common pipe connecting a settling tank for arresting the impurities, then passed to the recharge pit.

Ramani and Gupta (2000) conducted studies on rooftop rainwater harvesting in Indore city. The normal rainfall of Indore city was about 930mm, with total roof area of the project building being 2710mm^2. The total water available for recharge worked out to be 2520 cubic meter. It has been estimated that about 85 per cent of the available water was recharged since the balance of 15 per cent account for evaporation and conveyance losses etc. So the total recharge to ground water was worked out to be 2142 cubic meter.

Ravikumar and Anand (2000) conducted experiment on rooftop rainwater harvesting in Civil block, Bangalore University, J.B. Campus, Bangalore Karnataka. The annual average rainfall of this campus is 860mm and rainwater harvesting is necessary since the campus population depends only on groundwater. They adopted rainwater collection from the rooftop, in an area of 5500 sq. m.

Buttner (2001) conducted a study based on water scarcity as well as water disposal problem and harvested rain. New approaches in rain water harvesting take into account the inter connection between drinking water needs, sewage control, flooding and ground water accumulation. Rain water from rooftop is taken to underground tank via pipes and from there it is pumped for use in toilets, gardening and like purposes.

Kumar *et al*. (2001) carried out an estimation of rooftop rain water and design of recharge structures in Chennai airport terminal buildings. Thematic maps were designed in MAP INFO GIS software. Roof drainage was done in GIS environment. Curve number technique was employed in estimation of runoff. Based on the topography and lithography of airport, the artificial recharge were designed and located.

Patra (2010) deals with a case study of rain water harvesting method adopted in Dhanbad city of Jharkhand state. Dhanbad is one of the water scarce cities in India. Depending on precipitation intensity, rainwater constitutes a potential source of drinking water. Rainwater harvesting is the technology where surface runoff is effectively collected and stored. Harvested rainwater can then be used for drinking or for ground water recharge. Unless a proper water storage method is adopted, the rainwater harvesting may not be effective.

Aditya and Sneha (2011) deals with a case study of rain water harvesting method adopted in Dhanbad city of Jharkhand state. The proposed rooftop rainwater harvesting system is a low cost one the rainwater pipes are 110 mm diameter and are made of PVC. The areas of rooftop rainwater harvesting system are 1142.7 m^2. Dhanbad is a rain scarce city. Therefore it is expected that the rainwater harvesting will improve in the areas where rainfall is adequate and meet part of the water demand of the city.

2.2 Rainfall analysis

Modern agricultural methods comprising of moisture conservation techniques, use of improved varieties, application of chemical fertilizers etc., have considerably increased the input cost in rainfed farming. In rainfed farming, crop planning and its success is solely dependent upon the amount and distribution of rainfall. Rainfall distribution is most uneven and varies considerably from year to year. Hence, with the introduction of costly inputs in rainfed farming it has become imperative to use rainfall probabilities at different levels for crop planning. Several research workers have worked out the rainfall probabilities for the different agro-climatic regions of the country of which a brief review is done.

Gupta *et al.* (1985) developed an empirical relationship between seasonal and weekly rainfall and effective rainfall. The concept of average depth of available storage in the paddy field was used for estimating the weekly effective rainfall. Probability analysis was done to know the amount of effective rainfall at a desired chance level occurring in any week during the paddy growing period.

Verma and Sarma (1988) analysed of weekly rain fall for planning rainfed crop in Kandhi belt of Punjab to estimate the lowest assured weekly rainfall at different probability level using incomplete Gamma distribution. The results indicate that chance of drought is more at later stages of maize growth and there is scope for insitu moisture conservation measures and runoff collection in tanks for supplemental irrigation.

Kumar and Kumar (1989) collected rainfall data for 27 years to study the weekly, monthly, seasonal and yearly drought of Pantnagar. The observed frequency of drought was maximum in the 40th week which comes in November. Drought studies indicate that irrigation must be assured for sowing of Rabhi crops in November and also for the rest of the crop period. The chance of drought occurrence is once in three years.

Lee *et al.* (2000) studied on the scope of adopting rainwater cistern system in the tea farm of His–Ting area of Taiwan. Rain fall data of 38 years was analysed. To realize the severity of the water shortage in the area, minimum rainfall depths for different return period were examined. They concluded that serious tea farm damage will occur once in every two years if a rainwater cistern system not constructed in the area.

Prasad *et al.* (2000) was analysed 34 years of rainfall data from the rainfed belt of Ranchi, to estimate the least weekly rainfall at different probabilities using Weibull's plotting position formula. The results indicate that there is a chance of dry weeks at the later stage of Kharif season and there is scope for runoff collection in tanks for supplemental irrigation.

Ghosh *et al.* (2009) analyzed the trend of summer monsoon rainfall all over India at a finer spatial resolution (1° latitude × 1° longitude) to identify the places that have a significant trend in terms of both rainfall amount and occurrence. The present analysis shows spatially varying mixed responses of global warming toward rainfall occurrence and amounts all over India.

2.3 Water budgeting and water balance

Water budgeting or the moisture accounting method is a book keeping procedure to estimate moisture content by using climatological data. This is mostly base on the water balance equations and the approach varies depending upon the size of the area. Water budgeting allocates the available water to crops based on the water requirement. It helps irrigation engineers to distribute water required by the crop based on the water resources available and without any short or excess supply.

Gupta *et al.* (1985) estimated the weekly irrigation requirement of ten crop growing season by using the water balance approach from the data of the crop evapotranspiration, effective rain fall and percolation loss. This study demonstrates the use of irrigation requirement data of the paddy for its probabilistic estimation on weekly and seasonal time scale and suggestions have been made to design the irrigation system based on this.

Allen (1986) reviewed ten forms of the Penman combination evapotranspiration equation and compared with lysimeter estimates at three locations. The best estimates were given by Monteith method and Thom-Oliver method. The original Penman version underestimated Evapotranspiration in arid environment.

Siddeek *et al.* (1988) developed a methodology for estimating the weekly irrigation requirements of low land rice production that accounts for uncertainty in rainfall and crop evapotranspiration. This method is based on a water balance relationship that considers the stochastic nature of rainfall and evapotranspiration. It helps the irrigation system managers to determine the amount of irrigation water that will be required during the coming week to meet the crop demands at a given probability levels.

Etzenberg *et al.* (1997) attribute the growing importance of water balance studies to the change in climate and land use and temporal and spatial variability of water budget elements. They say that the water and energy balance, especially in the complex soil-vegetation- atmosphere system, requires an extensive data base. A long term water balance of representative basin was determined considering the importance of water balance studies for the solution of the ecosystem problems.

Fietz *et al.* (2001) studied the probability occurrence of water deficit in Dourados, Brazil based on daily data of evapotranspiration and rainfall over a period of approximately 20 years. The reference evapotranspiration was estimated by the FAO Penman- Monteith method. The daily water deficit was determined through a sequential water balance.

Robert *et al.* (2004) examined the water balance components from three small sub-arctic watersheds near Fairbanks, Alaska, USA, which vary in permafrost coverage from 3 to 53%. The results show that the presence or absence of permafrost affects many of the water balance components, particularly stream flow runoff and groundwater storage. Evapotranspiration, derived using the Priestley-Taylor method, averages between approximately 200–310 mm. During the snowmelt and summer runoff periods, the presence of poorly drained permafrost limits infiltration of surface waters, generating higher runoff than in comparable well-drained non-permafrost soils.

Jenifa *et al.* (2010) was developed a spatially semi- distributed water balance model to simulate mean monthly hydrological processes using landuse, soil texture, topography, and hydro-meteorological data as input parameters in the Amaravathi River Basin, a semiarid region of Tamil Nadu in India by. It is a physically based methodology for estimation of the average spatial distribution of water balance components. This model can be applicable in a public domain which can facilitate decision making.

2.4 On farm rain water harvesting

Rainfall harvesting in rainfed agricultural areas increases water availability for plants during the growing season, thus increasing crop production. Rainfall can be stored directly in the soil for crop production using terraces, contour ridges and other types of water collection methods. However, the efficiency of these methods is limited by the infiltration characteristics of soil and climatic conditions. Water harvesting can also be achieved by collecting runoff from catchments or micro catchments in tanks for human and animal consumption and for supplemental irrigation

Kolarkar *et al.* (1980) describe the water harvesting practices used in three different terrains in arid Western Rajasthan for growing crops. The catchment areas are either shallow rocky surfaces or shallow gravelly ridges and the cultivated farm lands are located in the low lying valleys. The simplest methods of water harvesting in all the three locations is to divert or slowly channelize the natural runoff from these catchments to the farm lands.

Athavale (1986) presented case studies of three representative stations in low rainfall area of the semi-arid tropics in India. Conjunctive use of rainfall, farm-harvested water and ground water at different crop stages, scheduling of the limited irrigation water available, benefits from supplementary irrigation etc. are dealt with. The rainfall pattern and the probability of occurrence of drought stress at critical periods of growth during a cropping season for the three areas are analysed.

Guerra *et al.* (1990) quantified the major hydrological parameters of four selected farm reservoirs using a water balance approach. Direct rainfall and runoff from the catchment area contributed, respectively, about 36 per cent 64 per cent to reservoir inflow. The minimum catchment area required to support a reservoir of given capacity was calculated to be nearly five times higher for a grassed catchment than for a catchment under paddy rice.

Rathore *et al.* (1996) was evaluated crop production potential of collection and use of excess rainfall occurring over a field area of 1.05 ha with deep vertisol in the eastern Madhya Pradesh region. The test strategy involved substitution of rice with upland crops like soyabean, pigeon pea and peanut in an approximately 0.66 ha area and the construction of small farm pond to collect the runoff from the field area under upland crops, to save rice from drought in the remaining 0.3 ha field area and the use of water saved in the farm pond at the end of rainy season for establishing post monsoon crops.

Srivastava (2001) developed simulation model to design a water harvesting system for the high rainfall areas of India. He concluded that in high rainfall areas of eastern India, a water harvesting system can facilitate timely transplantation of rice and proper utilization of the rainwater in addition to the prospect of second crop in the post monsoon season. The methodology of designing the system involved simulating water and tank water balance, selection of variety, criteria for the selection of desirable size of command area, and criteria for lining the tank.

Balram *et al*. (2007) carried out hydrologic and economic analysis of the on-farm reservoir (OFR) in rainfed rice–mustard cropping systems in Eastern India followed by 2 years of field experiments in 1999 and 2000. The average contribution (average of 2 years) of direct rainfall and surface runoff from the diked crop fields contributed, respectively, about 79.5 and 20.5% to the total OFR inflow. The average contribution of evaporation loss, seepage and percolation loss and supplemental irrigation from the OFR contributed, respectively, about 10.0, 31.2 and 58.8% to the total OFR outflow. There was an average increase of rice yield of 44.0% over the rainfed rice because of application of 8.4 cm supplemental irrigation from the OFR

Dipankar *et al.* (2009) develops a user-friendly software, using Visual Basic 6.0 program, to find out the optimal size of the OFR (On Farm Reservoir) in terms of percentage of field area by simulating the water balance model parameters of the crop field and the OFR. The water balance model parameters of the crop field are validated with 2 years of observed data from the experimental field of study area. The study reveals that rice–groundnut cropping system requires higher OFR sizes than rice–mustard cropping systems.

2.5 Ground water recharge

Ground water is a dynamic resource which is annually replenished. The replenishment takes place primarily through percolation of a fraction of the precipitation to aquifers, after passing through the unsaturated soil zone. Ground water recharge also occurs through seepage from lake and tank beds, channel flows and through the return flow of some of the water applied in irrigation.

Umrikar (1990) was done a scientific assessment and plan for the augmentation of the ground water by artificial recharge projects to meet the increasing demands of water needs in Maharashtra. He has outlined the existing hydro geological conditions with particular emphasis on ground water situation and need for undertaking the projects of artificial recharge and water conservation in various parts of the state. The objectives, benefits and suitability of the types of projects have been discussed and the evaluation of benefits and various experimental studies are presented to support the utility of the various projects.

Palanisami (1991) evaluated the recharge effects of 10 wells in and around Coimbatore. Analysis was done based on the ground water levels in the control and experimental wells. It was observed that the number of wells that benefited from the ponds were only 14 % of the total target wells. Wells located within 0.25 km radius from the ponds were benefited and the rising water level was less than 1 m.

Goyal *et al.* (1995) had undertaken a study to monitor the effect of soil and water conservation measures on erosion control and water recharge in Jhanwar watershed of Rajasthan. It was found that over a period of 8 years, structures like stone check dams, brush wood check dams etc., helped in arresting the soil to the tune of 312 Mg from an area of 30 ha. Ground water table in the area recorded average rise by 0.61 m per year. Besides this, constructed structures resulted in environment improvement by helping in establishment of natural vegetation in the eroded area.

Gopinath (1999) suggests that pits dug near wells help in the recharging of the wells in agricultural lands. His design is a 6 feet cubical pit connected to the wells with pipes at a depth of above 2 feet from the bottom of the pit, covered at the both ends with net to prevent clogging, contamination and silting of the wells. He also suggests 6 feet cubical filtering tanks as an alternative.

Raju (2001) observed that augmentation of ground water becomes necessary when a given area or basin the annual extraction exceeds annual replenishment. As water level decline below the phreatic aquifer, recharge of the deep aquifers becomes necessary. Deep aquifers can be recharged by surface techniques like gully plugs, contour bunds, bench terracing, percolation tank, individual well recharge etc. Subsurface recharge techniques include subsurface dykes and recharge tube wells.

Sharda *et al*. (2006) were estimated groundwater recharge from water storage structures under semi-arid conditions of western India by employing water table fluctuation (WTF) and chloride mass balance (CMB) methods. Groundwater recharge was estimated as 7.3% and 9.7% of the annual rainfall by WTF method for the years 2003 and 2004, respectively while the two years average recharge was estimated as 7.5% using CMB method. The study has revealed that a minimum of 104.3 mm cumulative rainfall is required to generate 1 mm of recharge from the water storage structures. An empirical linear relationship was found to reasonably correlate the changes in chloride concentration with water table rise or fall in the study area.

Daniele *et al.* (2011) develop a probabilistic modelling framework that quantifies the risk of a pond's infiltration capacity falling below its target value due to soil heterogeneity and clogging. Model enables one to account for a variety of maintenance strategies that target different clogging mechanisms. They find that physical clogging mechanisms induce the greatest uncertainty and that maintenance targeted at these can yield optimal results. They concluded that an adequate initial characterization of the surface infiltration ponds is crucial to determining the degree of uncertainty of different maintenance solutions and thus to making cost-effective and reliable decisions.

Chapter 3

MATERIALS AND METHODS

Detailed procedure used to work out the water budgeting of agricultural and non-agricultural areas in KCAET campus and design methodologies of various water harvesting systems are described in this chapter.

3.1 Description of the study area

The KCAET campus is situated at 10^0 52'30'' North Latitude and 76^0 East Longitude with a mean altitude of 914 m above mean sea level. The campus is spread over an area of 40.07 ha in which 30.66 ha are under agricultural use, 9.41 ha under office, residential and hostel buildings and the remaining area covers road, playground, fallow land etc.

3.1.1 Non agricultural areas

The building occupies 9.41 ha of the campus and information regarding their roof area, lawn area, number of persons working in the various departments, number of inmates of the hostels etc. are given in Appendix I.

3.1.2 Agricultural areas

The major crops cultivated in the campus are paddy, coconut, arecanut, fruit trees, banana, vegetables, other trees and fodder. The major crops with their respective areas are given in Appendix II.

3.2 Rain water harvesting potential

An assessment of the rain water harvesting potential of an area can be done based on the analyses of rainfall, soil, topography, water requirements etc. An attempt to study each of these factors of the study area was done and the details are furnished in the following sections.

3.2.1 Climate analysis

Climate and weather are the important integrated factors determining the status of agriculture. The influence of weather on crop performance is operative even before the crop seed is sown. The yield potential of a crop mainly depends on weather even though climate decides the choice of the crop. Hence an attempt was made to analyse the climatic data of KCAET for the coefficient of variation.

3.2.1.1 Coefficient of variation (CV)

The main features of rainfall variability namely its quantity and distribution is understood better by the analysis of CV. The variability of rainfall was determined by finding CV which is dimensionless measure and expressed in percentage.

$$\mathbf{CV = (SD / X) * 100}$$

where,

SD = Standard deviation

X = Mean

The rainfall data was collected from the meteorological observatory, KCAET.

3.2.2 Crop evapotranspiration

To estimate crop water requirements, the crop evapotranspiration was related to an estimated reference evapotranspiration by means of a crop coefficient.

$$\mathbf{ET_c = K_c \times ET_o}$$

where,

ET_c = Crop evapotranspiration

K_c = Crop coefficient

ET_o = Reference evapotranspiration

3.2.2.1 Estimation of reference evapotranspiration

The reference evapotranspiration is defined as the rate of evapotranspiration from a hypothetical crop with an assumed crop height (12 cm), and a fixed canopy resistance (70 s/m), and albedo (0.23), which would be closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground , and not short of water. According to this definition, the reference evapotranspiration was found from the following combination formula, which is based on the Penman-Monteith approach.

$$\mathbf{ETo = [\Delta / (\Delta+\gamma^*)]R'_n + [\gamma/(\Delta+\gamma^*)]E_a}$$

where,

ETo = Reference evapotranspiration, mm/d

Δ = Slope of vapour pressure curve at Ta, kPa /^{o}C

γ = Psychrometric constant, kPa / ^{o}C

γ^* = Modified psychrometric constant, kPa / ^{o}C

R'_n = Radiation evaporation equivalent, mm/d

E_a = Aerodynamic evaporation equivalent, mm/d

$\gamma = 1615\ (p_a / \lambda)$

where,

p_a = Atmospheric pressure, kPa

λ = Latent heat of vapourization, J / kg

$= 2.45 \times 10^6$

where,

$$p_a = 101.3 \left[(T_a + 273.16 - 0.0065H)/ (Ta + 273.16) \right]$$

H = Altitude above sea level, m

T_a = Average air temperature, ^{o} C

$T_a = [(T_{max} + T_{min})] / 2$

$\gamma^* = (1 + 0.337U_2)\ \gamma$

where,

U_2 = Wind speed measured at 2m height, m/s

The slope of the vapour pressure curve,

$$\mathbf{\Delta = (4098\ e_a)/(T_a+273.3)^2}$$

where,

e_a = saturated vapour pressure, kPa and

$$e_a = 0.6108 \exp\{(17.27\ T_a)/(T_a+237.3)\}$$

The radiative evaporation equivalent

$$R'_n = 86400\ (R_n-G) / \lambda$$

where,

R_n = Net radiation at the crop surface, W/m^2

G = Heat flux density of the soil, W/m^2

Net radiation,

$$R_n = R_{ns} - R_{nl}$$

Net short wave radiation, $R_{ns}= (1-\alpha)\ R_s$

where,

α = Albedo or canopy reflection coefficient, 0.23

R_s = Solar radiation, W/m^2

The net long wave radiation,

$$R_{nl} = [0.9\ (n/N)+0.1][0.34-0.139\sqrt{e_d}\ ][\sigma\ (TK^4_{max} + TK^4_{min})/2]$$

where,

R_{nl} = net long wave radiation, W/ m^2

n = Daily duration of bright sunshine, h

N = Day length, h

e_d = Actual vapour pressure, kPa

TK_{max} = Maximum absolute temperature, K

TK_{min} = Minimum absolute temperature, K

σ = Stefan-Boltzman constant, $Wm^{-2}K^{-4}$; 5.6745×10^{-8}

The actual vapour pressure, $e_d = (RH/100)\ e_a$

where,

RH = relative humidity, percent

The aerodynamic evaporation equivalent was computed from

$$E_a = [900/(T_a+275)]\ u_2(e_a - e_d)$$

The climatologic data for one year were collected from the Meteorological observatory, Tavanur and the weekly average is given in Appendix III.

3.2.2.2 Crop coefficients

The crop evapotranspiration of a crop represents its crop water requirement and it is found by multiplying the reference evapotranspiration with the respective crop coefficient. The values of crop coefficients for the different crops in the campus are given in Table 3.1. Since K_c value varies with stages of crop, an average value was taken for this purpose.

3.2.3 Soil properties

An attempt was made to establish the important physical properties of the various soil types of KCAET campus. Mechanical analysis was done to get the true representation of grain size distribution. In-situ bulk density was determined by core cutter method and the hydraulic conductivity was found from the falling head permeability test. The rate of entry of water into the soil was determined using double ring infiltrometer. These properties were found out as they are related to the movement of water into and through the soil.

Table 3.1 Crop coefficient (Kc) Values

Sl No	Crops	K_c
1	Banana	0.98
2	Coconut	0.90
3	Fruit trees	0.52
4	Fodder	0.75
5	Grass	0.85
6	Paddy	1.10
7	Trees	0.60
8	Vegetables	0.50

3.2.4 Contour map of the area

The contour map of the study area was prepared with the demarcation of location of the wells.

3.2.5 Water budgeting studies for KCAET campus

Water budgeting studies aimed at equitable distribution of the available water resources was done for the non-agricultural and agricultural areas of KCAET campus. The important parameters in the water balance equation, namely precipitation and evapotranspiration, are used in the analysis of the supply demand situation. The study aims at finding the extent to which the various demands can be met through rainwater harvesting.

3.2.5.1 Water budgeting of non-agricultural areas

A survey was conducted to evaluate the weekly water demand for various purposes like drinking, gardening, laboratory use, cooking, bathing, washing etc., of the offices, staff residences and hostels. The data collected were used to calculate the water demands for the various purposes. This demand was compared to the effective runoff potential of the individual rooftops. Surplus/deficit water in each week was also worked out with this information. The volume of rainwater that can be collected from the rooftops was calculated by using the formula

$$V_r = C \times d \times A$$

where,

V_r = Volume of rainwater harvested from roof per week, m^3

C = Runoff coefficient

d = Depth of rainfall, m

A =Area of the roof surface, m^2

The runoff coefficient ranges from 0.8 to 0.90 for different roof surfaces. In this study an average of 0.85 was taken as C.

3.2.5.2 Water budgeting of agricultural areas

Rainfall and crop evapotranspiration are the major parameters involved in the estimation of irrigation requirement of a crop. Crop evapotranspiration was estimated as explained in 3.2.2. The difference between the crop evapotranspiration and the rainfall gives the irrigation water requirement of the crop for a week. Weekly irrigation demand for each crop was got by multiplying the water requirement with total area under each crop. Surplus/deficit water in each week was also estimated.

3.3 Roof top rain water harvesting potential

The vitality and utility of conserving the rain that fall on the roof tops was well understood.

3.3.1 Design of roof top rain water harvesting structures

The basic design procedure for a roof top water harvesting system is described. The main components of such a system are

1. Roof top catchment area
2. Gutters
3. Down pipe and first flush pipe
4. Diversion pipes to detention/settling tank
5. Filter unit

6. Storage tank
7. Recharge pit

The design procedure of the roof top water harvesting system is described below.

3.3.1.1 Catchment area

The roof top area was calculated using the basic formula,

$$\mathbf{A = L \times B}$$

where,

A = Area of the rectangle, m^2

L = Length, m

B = Breadth, m

3.3.1.2 Gutters

Gutters receive the rain falling on the roof surface and direct it towards the down pipe. The size and number of gutters were selected based on the peak intensity of rain of the area. Gutters can be made of plain galvanized iron sheet of 18 gauge or 20 gauge, PVC pipes cut into two at the middle or even bamboo splits. For residential buildings, gutters of semi-circular shape with a 0.5 per cent slope can be made. The radius of the gutter can be calculated as follows.

Volume of water harvested, m^3s^{-1} = Runoff coefficient x Roof top area x Rainfall intensity

$$\mathbf{Q_g = A \times V_m}$$

where,

Q_g = Gutter discharge, m^3s^{-1}

A = Area of semicircular section, m^2

V_m = Maximum velocity, m/s

$$A = \pi r^2 / 2$$

where,

r = Radius of the semicircular section, m

$$V_m = (1/n)(R)^{2/3}(S)^{1/2}$$

where,

n = Manning's roughness coefficient (0.016 for GI sheet and 0.009 for PVC pipes)

R = Hydraulic radius ; $R = (\pi r^2 / 2) / \pi r$

S = Slope

From these equations the radius of the gutter can be found.

3.3.1.3 Down pipe

The down pipe receives the water from the outlet end of the gutters or carries the water down from concrete terrace roofs as the case may be. The height of the building determines the length of the down pipe. GI pipes, asbestos cement pipes or PVC pipes can be used as down pipes. The size of the pipe can be selected depending on the water collected from the roof surface.

Volume of water harvested, m^3/s = Runoff coefficient x Roof top area x Rainfall intensity

$$\mathbf{Q_d = A \times V}$$

where,

Q_d = Discharge through down pipe, m^3/s

A = Cross section of the pipe, m^2

V = Velocity of water, m/s

$$A = (\pi/4)\, d^2$$

where,

d = Diameter of the pipe, m

$$V = \sqrt{(Hdg)/2fl}$$

where,

H = Head causing flow, m

g = Acceleration due to gravity, m/s^2

f = Darcy's roughness coefficient

l = Length of the pipe, m

d = Diameter of the pipe, m

3.3.1.4 Diversion pipes to detention basin

From the down pipe the water can be diverted through PVC pipes to the detention basin. If the pipe is given a slope the water can be taken up to the detention tank by gravity flow. The diameter of the pipe was calculated as below.

Volume of water harvested, m^3/s = Runoff coefficient x Roof top area x Rainfall intensity

$$Q = A \times V$$

where,

Q = Rate of flow, m^3/s

A = Cross section of the pipe, m^2

V = Velocity of flow of water through the pipe, m/s

A = $(\pi/4)\, d^2$

where,

d = Diameter of the pipe, m

$$V = 1/n\, R^{2/3}\, S^{1/2}$$

where,

n = Manning's roughness coefficient

R = Hydraulic radius = d/4

S = Slope factor

3.3.1.5 Detention basin

Treatment of rain water is essential to make it potable. Detention tanks helps in settling the larger inorganic impurities and also reduces the velocity of the rain water during intense rain. The walls of the detention basin can be made with II class chamber burned bricks with cement mortar 1:5 and the inner walls can be plastered with 1:5 cement mortar of 12 mm thickness. The flooring can be done of cement concrete 1:5:10. The size of the detention basin was calculated based on Stoke's law.

$$T = (0.03\eta D_v)/[(D_p\text{-}D)\ 4r^2]$$

where,

T = Time taken for particles to fall a vertical distance D_v

D_v = Vertical distance through which the particle falls, m

r = Radius of particles, m

D_p = Density of particles, g/cc

D = Density of water, g/cc

η = Viscosity of water, g/cm-sec

3.3.1.6 Filter unit

In the filter unit, water is passed through a thick layer of sand and gravel. The suspended and colloidal impurities present in water, in a finely divided state, are removed to a greater extend. This reduces the bacterial activity in water. For domestic consumption this component is essential for treating rainwater. The materials used for construction are same as that of detention tank. The design is based on the following formulae.

Discharge of water per minute = Runoff coefficient x Roof area x Rainfall intensity

Total surface area required = Maximum discharge/ Rate of filtration

3.3.1.6.1 Gravel for filtering tank

Gravel is used as the base material in the filtering basin. Gravel of sizes 40, 25 and 15 mm can be used. For a tank of 1 m height, 40 mm size gravel can be placed for 20 cm, 25 mm size for another 20 cm and 50 mm size upto 20 cm from bottom to top.

3.3.1.6.2 Sand for the filter unit

The effective size of sand varies from 0.35 to 0.6 mm. Coarse sand can be laid to a height of 20 cm above which layer of fine sand of 20 cm thickness can be laid.

3.3.1.7 Storage tank

The water collected in the storage tank can be used to tie over periods of insufficient rainfall. The cost of the tank can be reduced by using cheaper construction materials and techniques. Here we can adopt a brick walled tank.

Maximum quantity of water harvested = Runoff coefficient x Depth of rainfall x Roof area

Size of the tank was computed based on this volume.

3.3.1.8 Recharge pit

Water, if any, that cannot stored can be diverted to recharge pits dug in the available space

Capacity of recharge pit = Water collected/ Voids ratio

3.4 Water harvesting in agricultural areas

Rainwater harvesting has a key role in augmenting the campus water resources. It has been observed that during intense rain the rainwater produces a surface sealing and hence is lost as surface runoff. This prevents the replenishment of the groundwater and hence resulted in the poor state of the water table. As the agricultural operations in the campus farm depend on water from the wells, it is imperative that the aquifers be recharged. The runoff should be collected in tanks/ponds. So that it can be used during the dry periods or else to act as percolation tanks.

3.4.1 Design of percolation ponds

Percolation ponds are small water storage structures constructed to collect and impound surface runoff from the catchments during rains and store it for longer time. They are multipurpose structures storing water for irrigation or to augment the groundwater recharge. Site for such ponds were identified based on all the parameters discussed earlier and on the availability of land. The steps for the design of the pond are given below.

Step 1: Estimation of water yield from the catchment using one of the following method

a. Curve number method

b. Methods of approximation

Step 2: Determination of capacity of the pond

Capacities of the ponds were found assuming that 30% of the water yield was harvested in the pond and considering that three fillings are possible.

Step 3: Cross section of the bund and body wall

Based on the contour map of the selected site, the area capacity curve was developed relating storage capacity of the tank and depth of storage. For each site, the contour which can store the design capacity was selected. The side slope varies with the type of soil. The top width of the bund is recommended to be in the range of 1 to 2.5 m.

Step 4: Design of surplus weir

Wing wall type weir was selected as the surplusing arrangement as the drop from the top of weir to the bed level of the tail channel exceeds 1 m. the weir consists of body walls, abutments, wing wall, returns, apron and talus.

3.4.2 Runoff collection in abandoned wells

Groundwater recharge using the open wells is a cost effective method by which the abandoned open wells can be put under use for rainwater harvesting. As the agricultural operations in the campus depend on ground water, it is imperative that the aquifers be recharged. The abandoned wells within the campus can serve the purpose of subterranean water injection sinks.

Chapter 4

RESULT AND DISCUSSION

Water harvesting has become the order of the day in most parts of our world on account of the vagaries of monsoon, mismanagement of irrigation water and over exploitation of surface and subterranean water storage for domestic, agricultural and industrial needs. The primary objective of any water harvesting system is to arrive at optimal water budgeting in order to sustain crop production and to provide water reserve for domestic and industrial usage. The analyses of meteorological data, determination of soil properties and land slope and investigation of ground water status formed the essential basis for water budgeting, optimal water allocation and design of water harvesting systems for the study area.

4.1 Climate analysis

One year data was used for the analysis.

4.1.1 Rainfall variability

The mean weekly rainfall and the coefficient of variation are presented in Table 4.1. From the observation of the mean weekly rainfall, the weeks over which the South West monsoon and North East monsoon are distributed can be understood. Mean weekly rainfall of more than 30 mm is recorded in the standard weeks of 22, 35, 36, 41, 45 and 48. The total mean annual rainfall comes to 529.57 mm.

The computed coefficient of variation (CV) values lie between the threshold values of 100 and 150 percent in 10 weeks. This indicates lesser rainfall variability during these weeks. Hence the rainfall averages for the weeks 5, 6, 8, 35, 38, 39, 46, 48, 49, 51 are dependable. The rainfall variability values over the weeks will enable better planning on a sustainable basis. It can be generalized that greater the CV lesser is the dependability and for lower rainfalls greater will be the value of CV.

Table 4.1 Mean weekly rainfall and coefficient of variation

Std. weeks	Month and date	Mean rainfall (mm)	SD	CV (%)	Std. weeks	Month and date	Mean rainfall (mm)	SD	CV (%)
1	OCT 01-07	0	0	0	27	APR 02-08	1.14	2.27	198.9
2	OCT 08-14	0	0	0	28	APR 09-15	6.71	13.2	197.5
3	OCT 15-21	0	0	0	29	APR 16-22	6.71	10.84	161.6
4	OCT 22-28	53.14	90.61	170.5	30	APR 23-29	6.28	11.01	175.4
5	OCT 23-NOV 04	13.71	19.67	143.4	31	APR 30-MAY 06	1.43	3.78	226.3
6	NOV 05-11	6.142	6.47	105.3	32	MAY 7-13	0	0.38	264.3
7	NOV 12-18	9	6.06	67.3	33	MAY 14-20	0	0	0
8	NOV 19-25	3.29	3.73	113.3	34	MAY 21-27	1.28	2.63	205.3
9	NOV 26-DEC 02	0.286	0.76	265.6	35	MAY 28-JUN 03	41.71	42.58	102.1
10	DEC 03-09	0	0	0	36	JUN 4-10	30.85	23.13	74.96
11	DEC 10-16	0	0	0	37	JUN 11-17	28.71	17.57	61.18
12	DEC 17-23	0	0	0	38	JUN 18-24	14.71	15.86	107.8
13	DEC 24-31	0	0	0	39	JUN 25-JUL 1	11.29	12.05	106.74
14	JAN 01-07	0.86	2.27	263.6	40	JUL 2-8	22.82	38.98	170.8
15	JAN 08-14	0	0	0	41	JUL 9-15	39.57	72.85	184.1
16	JAN 15-21	0	0	0	42	JUL 16-22	21.142	16.30	77.1
17	JAN 22-28	0	0	0	43	JUL 23-29	8.42	6.75	80.2
18	JAN 29-FEB 4	0	0	0	44	JUL 30-AUG 5	20	17.85	89
19	FEB 05-11	0	0	0	45	AUG 6-12	30.85	30.22	97.97
20	FEB 12 18	0	0	0	46	AUG 13-19	3.85	4.45	115.6
21	FEB 19-25	7.28	17.99	247	47	AUG 20-26	10.43	9.38	89.9
22	FEB 26-MAR 4	54.85	145.1	264.6	48	AUG 27-SEP 2	30.14	32.21	106.9
23	MAR 5 -11	3.57	9.02	252.6	49	SEP 3-9	17.4	15.59	107.5
24	MAR 12-18	0	0	0	50	SEP 10-16	18	16.49	91.6
25	MAR 19-25	0	0	0	51	SEP 17-23	3.57	3.95	110.7
26	MAR 26 – APR 1	0.29	0.76	260.7	52	SEP 24-30	0.143	0.38	264.3

4.2 Soil property

The results of in-situ bulk density, hydraulic conductivity and infiltration rate of different soils are shown in Table 4.2.

Table 4.2 Properties of soils in the study area

Soil type	In-situ BD (g/cm^3)	Saturated Hydraulic Conductivity (m/h)	Infiltration (m/h)
Sand	1.802	0.059	0.18
Sandy-loam	1.84	0.010	0.07
Clay	1.97	0.009	0.008

4.2.1 Saturated hydraulic conductivity and infiltration rate

The hydraulic conductivity of different soils reflects the water transmission power of soil. We can see that the hydraulic conductivity is more for sand. This higher value causes very rapid downward movement of water. The rapid infiltration rate in sandy soil is because of the relatively coarse texture. The higher bulk density in clay is due to the fact that the finer fractions filling up the macropores and provide compaction. The high bulk density should have beneficial effect on moisture holding capacity.

4.2.2 Land use map of the study area

The land use map of the study is given in Fig.1.

4.3 Contour map

Fig. 2 shows the contour map of the study area. It also shows the locations of different wells of the study area. So that we can assess the existing water supplies within the campus.

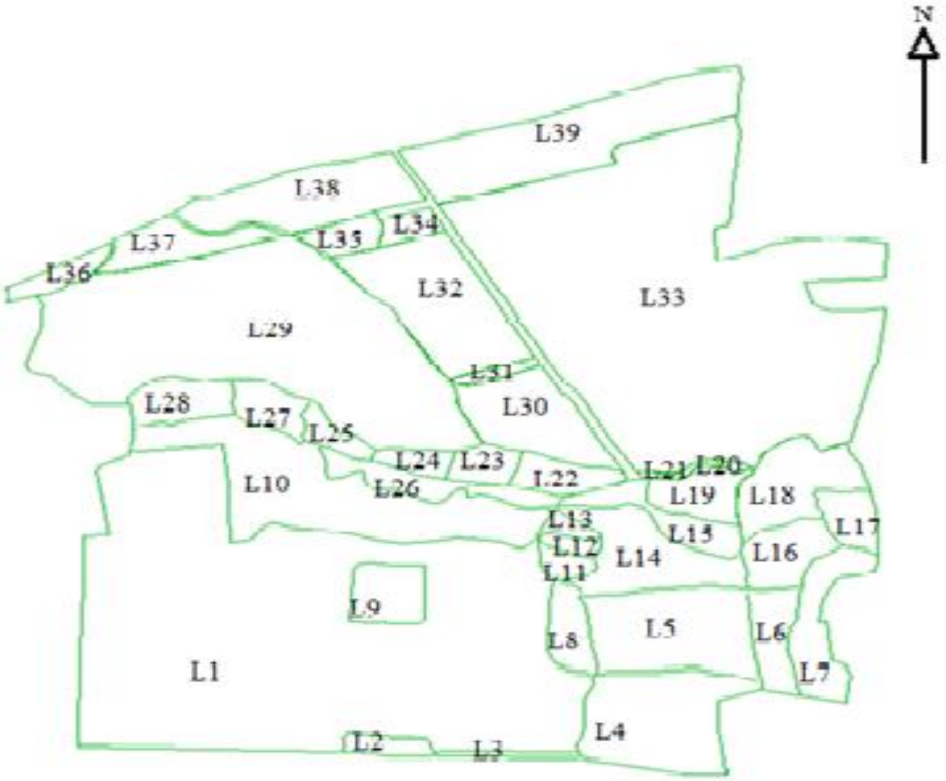

Fig. 1 Land use map of the KCAET campus

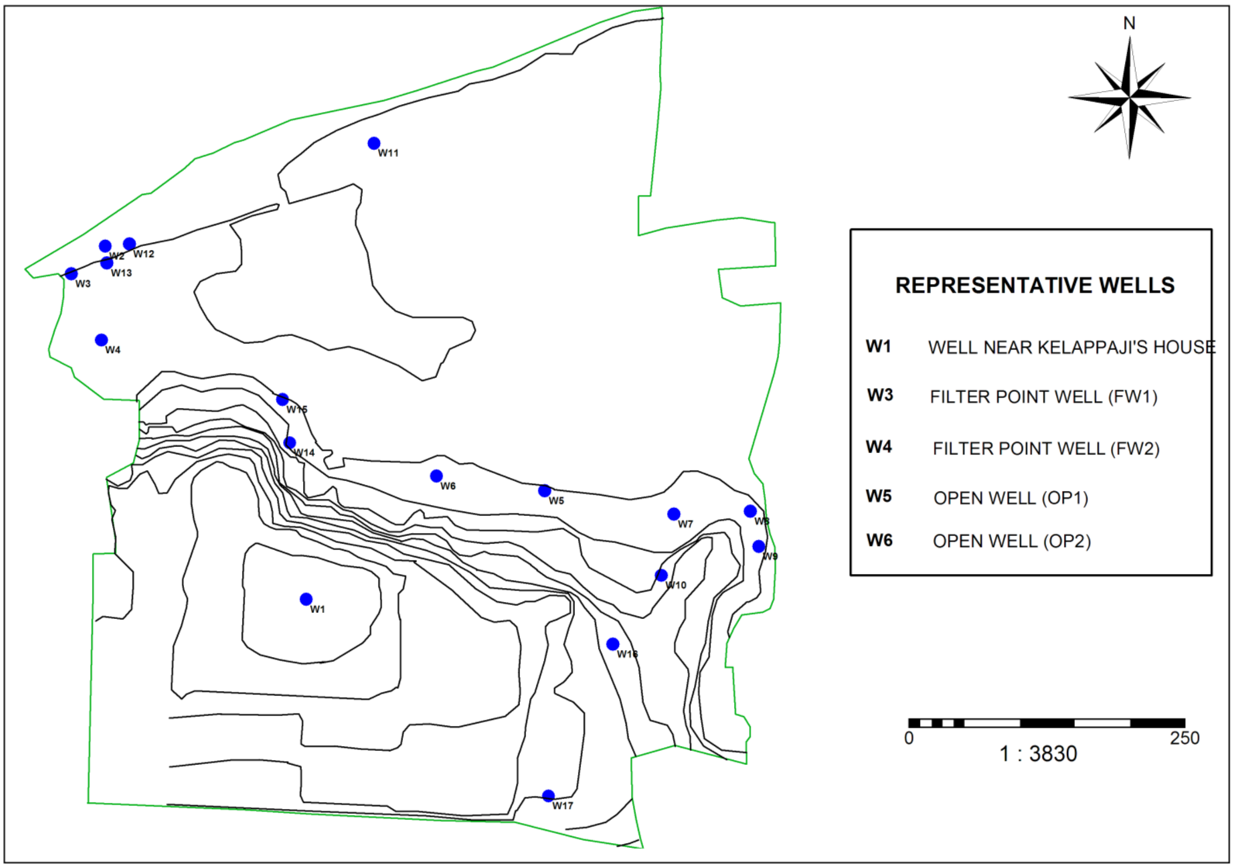

Fig. 2 Contour map of study area

4.4 Water budgeting studies

An accounting of the credits and debits of water for the entire study area was done and is discussed in the following sections. Water is credited by rainfall and the debits include evapotranspiration in agricultural areas and drinking, cooking, sanitary and laboratory demands in the various buildings. The latter is included as water budgeting of non-agricultural areas. The water balance components viz. rainfall and evapotranspiration were computed as described in earlier sections. (Weekly rainfall at 50 per cent probability was taken for the water budgeting studies).

4.4.1 Water budgeting of non-agricultural areas

The buildings in KCAET campus were categorized based on the nature of demands as office buildings, residential buildings and hostels. The various water demands were estimated based on the survey conducted. It was observed that the average drinking water demand per person per day was 2 litres. Sanitary needs and requirements for gardening, washing vehicles etc. varied with the status of the individual. The average values taken for computation are given below. Water required for washing clothes, floors, utensils and in toilets are included under the head of sanitary needs. Miscellaneous needs account for gardening, washing vehicles etc.

Table 4.3 Water demand

Demand / person / day (litres)	Purpose					
	Drinking	Cooking	Bathing	Sanitary	Miscellaneous	Total
Residences and hostels	2	5	40	70	25	137
Office	2	-	-	10	-	12

4.4.1.1 Water budgeting of office buildings

The buildings which accommodate the various departments, laboratories and administrative office are included in this category. The roof area of all such buildings together comes to 26261 m^2. The roof top water harvesting potential found by multiplying the mean weekly rainfall with roof area and the runoff coefficient is 11824.22 m^2 as shown in table 4.5. The total number of persons working in these buildings is 144 and the area of lawns in the whole campus is 710 m^2. The weekly irrigation requirement of the lawns and the water demand for drinking, sanitary, and laboratory purposes are given in the Table 4.4. These values are worked out assuming that the offices function for 6 days a week.

The total demand for water in a year is about 4080 $m^3$and water harvested from roof tops covers 11824.22 m^3. This provides a surplus of 7744 m^3. This shows that the water harvested from roof top is 2.8 times more than the demand. From the analysis of weekly deficit/surplus it is seen that the standard weeks 4-7, 21-23, 28-30 and 35-51 shows surplus. This surplus water which comes to 9506.96 m^3 is sufficient to meet the total water deficit for the remaining weeks.

Table 4.4 Water budgeting of office buildings

Std. week	Rain fall (mm)	RTWH (m^3)	ET (mm)		WR (lawn)	Water demand (m^3)				Surplus/ Deficit (m^3)
			ETo	ET (lawn)		Drinking	Sanitary	Lab	Total	
1	0	0	6.69	5.68	4.03	1.728	60.48	12	78.24	-78.24
2	0	0	6.97	5.93	4.21	1.728	60.48	12	78.42	-78.42
3	0	0	6.54	5.56	3.95	1.728	60.48	12	78.16	-78.16
4	53.14	1186.18	6.98	5.69	4.04	1.728	60.48	12	78.25	1108
5	13.71	306.03	6.47	5.5	3.91	1.728	60.48	12	78.11	227.9
6	6.14	137.10	6.34	5.39	3.83	1.728	60.48	12	78.03	59.07
7	9	200.90	6.98	5.42	3.85	1.728	60.48	12	78.06	122.8
8	3.29	73.44	6.2	5.27	3.74	1.728	60.48	12	77.95	-4.51
9	0.29	6.38	6.26	5.32	3.78	1.728	60.48	12	77.99	-71.61
10	0	0	5.94	5.05	3.59	1.728	60.48	12	77.79	-77.79
11	0	0	6.15	5.22	3.71	1.728	60.48	12	77.91	-77.91
12	0	0	6.24	5.31	3.77	1.728	60.48	12	77.98	-77.98
13	0	0	6.31	5.36	3.81	1.728	60.48	12	78.01	-78.01
14	0.86	19.20	6.59	5.6	3.98	1.728	60.48	12	78.18	-58.98
15	0	0	5.81	4.94	3.51	1.728	60.48	12	77.72	-77.72
16	0	0	6.01	5.12	3.64	1.728	60.48	12	77.84	-77.84
17	0	0	5.66	4.81	3.42	1.728	60.48	12	77.62	-77.62
18	0	0	8.02	4.82	3.42	1.728	60.48	12	77.63	-77.63
19	0	0	7.6	8.46	6.01	1.728	60.48	12	80.21	-80.21
20	0	0	7.19	6.11	4.34	1.728	60.48	12	78.55	-78.55
21	7.28	162.50	6.78	5.76	4.09	1.728	60.48	12	78.3	84.2
22	54.85	1224.35	7.8	6.64	4.71	1.728	60.48	12	78.92	1145
23	3.57	79.69	7.66	6.51	4.62	1.728	60.48	12	78.83	0.86
24	0	0	8.17	6.91	4.91	1.728	60.48	12	79.11	-79.11
25	0	0	7.69	6.53	4.64	1.728	60.48	12	78.84	-78.84
26	0.29	6.47	7.89	6.71	4.76	1.728	60.48	12	78.97	-72.5

Table 4.4 Water budgeting of office buildings (contd.)

Std. week	Rain fall (mm)	RTWH (m^3)	ET (mm)		Water demand (m^3) ETo					Surplus /Deficit (m^3)
			ETo	ET (lawn)	WR (lawn)	Drinking	Sanitary	Lab	Total	
27	1.14	25.45	7.81	6.64	4.71	1.728	60.48	12	78.92	-53.47
28	6.71	149.78	8.15	6.93	4.92	1.728	60.48	12	79.13	70.65
29	6.71	149.78	7.74	6.58	4.67	1.728	60.48	12	78.88	70.9
30	6.28	140.18	7.51	6.38	4.53	1.728	60.48	12	78.74	61.44
31	1.43	31.92	7.79	6.62	4.7	1.728	60.48	12	78.91	-46.99
32	0	3.19	7.9	6.72	4.77	1.728	60.48	12	78.98	-75.79
33	0	0	8.05	6.85	4.86	1.728	60.48	12	79.07	-79.07
34	1.28	28.57	7.87	6.89	4.89	1.728	60.48	12	79.1	-50.53
35	41.71	931.04	7.72	6.56	4.66	1.728	60.48	12	78.87	852.2
36	30.85	688.63	7.13	6.06	4.3	1.728	60.48	12	78.51	610.1
37	28.71	640.86	7.05	6	4.26	1.728	60.48	12	78.47	562.4
38	14.71	328.35	7.04	5.98	4.25	1.728	60.48	12	78.45	249.9
39	11.29	252.01	7.3	6.21	4.41	1.728	60.48	12	78.62	173.4
40	22.82	509.38	7.27	6.18	4.39	1.728	60.48	12	78.6	430.8
41	39.57	883.28	6.99	5.94	4.22	1.728	60.48	12	78.43	804.9
42	21.14	471.93	6.93	5.89	4.18	1.728	60.48	12	78.39	393.5
43	8.42	187.95	7.07	6.01	4.27	1.728	60.48	12	78.48	109.5
44	20	446.44	6.77	5.75	4.08	1.728	60.48	12	78.29	368.1
45	30.85	688.63	7.05	5.99	4.25	1.728	60.48	12	78.46	610.2
46	3.85	85.94	6.99	5.94	4.22	1.728	60.48	12	78.43	7.515
47	10.43	232.82	7.01	5.96	4.23	1.728	60.48	12	78.44	154.4
48	30.14	672.78	6.97	5.23	3.71	1.728	60.48	12	77.92	594.9
49	17.4	388.40	7.01	6.04	4.29	1.728	60.48	12	78.5	309.9
50	18	401.79	7.03	5.98	4.25	1.728	60.48	12	78.45	323.3
51	3.57	79.69	7.29	6.14	4.36	1.728	60.48	12	78.57	1.123
52	0.143	3.19	7.37	6.27	4.45	1.728	60.48	12	78.66	-75.47
Total	529.57	11824.22	368	311.36	221	89.86	3144.96	624	4080	7744

4.4.1.2 Water budgeting of residential building

The total roof area of such buildings together was found to be 3465 m^2. The survey results show that there are 78 persons occupying these buildings. The roof water harvesting potential of the residential building is calculated to be around 1609.78 m^3 and the water needed to meet the various demand is 4031.56 m^3. The detailed accounting is given in table 4.5. There is a shortage of 2421.78 m^3 of water to satisfy the demands completely from harvested roof water. From the analysis of weekly deficit/ surplus it is seem that except in the standard weeks 4, 22, 35-37, 41 and 48 all other weeks shows a deficit.

Table 4.5 Water budgeting of residential building

Std. week	Rain fall (mm)	RTWH (m^3)	Water demand (m^3)						Surplus/ Deficit (m^3)
			Drinking	Cooking	Bathing	Sanitary	Misc.	Total	
1	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
2	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
3	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
4	53.14	156.51	1.092	2.73	21.84	38.22	13.65	77.53	78.98
5	13.71	40.38	1.092	2.73	21.84	38.22	13.65	77.53	-37.15
6	6.14	18.1	1.092	2.73	21.84	38.22	13.65	77.53	-59.43
7	9	26.5	1.092	2.73	21.84	38.22	13.65	77.53	-51.03
8	3.29	9.69	1.092	2.73	21.84	38.22	13.65	77.53	-67.84
9	0.29	0.85	1.092	2.73	21.84	38.22	13.65	77.53	-76.68
10	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
11	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
12	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
13	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
14	0.86	2.53	1.092	2.73	21.84	38.22	13.65	77.53	-75
15	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
16	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
17	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
18	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
19	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
20	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
21	7.28	21.44	1.092	2.73	21.84	38.22	13.65	77.53	-56.09
22	54.85	161.55	1.092	2.73	21.84	38.22	13.65	77.53	84.02

Std. week	Rain fall (mm)	RTWH (m^3)	Water demand (m^3)						Surplus/ Deficit (m^3)
			Drinking	Cooking	Bathing	Sanitary	Misc.	Total	
23	3.57	10.51	1.092	2.73	21.84	38.22	13.65	77.53	-67.02
24	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
25	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
26	0.29	0.85	1.092	2.73	21.84	38.22	13.65	77.53	-76.68
27	1.14	3.36	1.092	2.73	21.84	38.22	13.65	77.53	-74.17
28	6.71	19.76	1.092	2.73	21.84	38.22	13.65	77.53	-57.77
29	6.71	19.76	1.092	2.73	21.84	38.22	13.65	77.53	-57.77
30	6.28	18.5	1.092	2.73	21.84	38.22	13.65	77.53	-59.03
31	1.43	4.21	1.092	2.73	21.84	38.22	13.65	77.53	-73.32
32	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
33	0	0	1.092	2.73	21.84	38.22	13.65	77.53	-77.53
34	1.28	3.77	1.092	2.73	21.84	38.22	13.65	77.53	-73.76
35	41.71	122.85	1.092	2.73	21.84	38.22	13.65	77.53	45.32
36	30.85	90.86	1.092	2.73	21.84	38.22	13.65	77.53	13.33
37	28.71	84.56	1.092	2.73	21.84	38.22	13.65	77.53	7.03
38	14.71	43.32	1.092	2.73	21.84	38.22	13.65	77.53	-34.21
39	11.29	33.25	1.092	2.73	21.84	38.22	13.65	77.53	-44.28
40	22.82	67.21	1.092	2.73	21.84	38.22	13.65	77.53	-10.32
41	39.57	116.54	1.092	2.73	21.84	38.22	13.65	77.53	39.01
42	21.14	62.26	1.092	2.73	21.84	38.22	13.65	77.53	-15.27
43	8.42	24.8	1.092	2.73	21.84	38.22	13.65	77.53	-52.73
44	20	58.91	1.092	2.73	21.84	38.22	13.65	77.53	-18.62
45	30.85	90.86	1.092	2.73	21.84	38.22	13.65	77.53	13.33
46	3.85	11.34	1.092	2.73	21.84	38.22	13.65	77.53	-66.19
47	10.43	30.72	1.092	2.73	21.84	38.22	13.65	77.53	-46.81
48	30.14	88.77	1.092	2.73	21.84	38.22	13.65	77.53	11.24
49	17.4	51.25	1.092	2.73	21.84	38.22	13.65	77.53	-26.28
50	18	53.01	1.092	2.73	21.84	38.22	13.65	77.53	-24.52
51	3.57	10	1.092	2.73	21.84	38.22	13.65	77.53	-67.53
52	0.143	51	1.092	2.73	21.84	38.22	13.65	77.53	-26.53
Total	529.57	1609.78	56.784	141.96	1135.68	1987.44	709.8	4031.56	-2421.78

4.4.1.3 Water budgeting of hostels

The total roof area of such buildings together was found to be 4728 m^2. The survey result shows that there are 178 persons occupying these buildings. The potential of roof top water harvested comes to only 2128.2 m^3 while the total demand is of the order of 9200.36 m^3. From table 4.6 it is seen that there is a deficit of water for meeting the demands.

Table 4.6 Water budgeting of hostels

Std. week	Rain fall (mm)	RTWH (m^3)	Water demand (m^3)						Surplus/Deficit (m^3)
			Drinking	Cooking	Bathing	Sanitary	Misc.	Total	
1	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
2	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
3	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
4	53.14	213.56	2.492	6.23	49.84	87.22	31.15	176.93	36.629
5	13.71	55.098	2.492	6.23	49.84	87.22	31.15	176.93	-121.83
6	6.14	24.675	2.492	6.23	49.84	87.22	31.15	176.93	-152.25
7	9	36.169	2.492	6.23	49.84	87.22	31.15	176.93	-140.76
8	3.29	13.222	2.492	6.23	49.84	87.22	31.15	176.93	-163.71
9	0.29	1.1655	2.492	6.23	49.84	87.22	31.15	176.93	-175.76
10	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
11	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
12	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
13	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
14	0.86	3.4562	2.492	6.23	49.84	87.22	31.15	176.93	-173.47
15	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
16	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
17	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
18	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
19	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
20	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
21	7.28	29.257	2.492	6.23	49.84	87.22	31.15	176.93	-147.67
22	54.85	220.43	2.492	6.23	49.84	87.22	31.15	176.93	43.5012
23	3.57	14.347	2.492	6.23	49.84	87.22	31.15	176.93	-162.58
24	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93

Std. week	Rain fall (mm)	RTWH (m^3)	Water demand (m^3)						Surplus/Deficit (m^3)
			Drinking	Cooking	Bathing	Sanitary	Misc.	Total	
25	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
26	0.29	1.1655	2.492	6.23	49.84	87.22	31.15	176.93	-175.76
27	1.14	4.5814	2.492	6.23	49.84	87.22	31.15	176.93	-172.35
28	6.71	26.966	2.492	6.23	49.84	87.22	31.15	176.93	-149.96
29	6.71	26.966	2.492	6.23	49.84	87.22	31.15	176.93	-149.96
30	6.28	25.238	2.492	6.23	49.84	87.22	31.15	176.93	-151.69
31	1.43	5.7469	2.492	6.23	49.84	87.22	31.15	176.93	-171.18
32	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
33	0	0	2.492	6.23	49.84	87.22	31.15	176.93	-176.93
34	1.28	5.1441	2.492	6.23	49.84	87.22	31.15	176.93	-171.79
35	41.71	167.62	2.492	6.23	49.84	87.22	31.15	176.93	-9.3058
36	30.85	123.98	2.492	6.23	49.84	87.22	31.15	176.93	-52.95
37	28.71	115.38	2.492	6.23	49.84	87.22	31.15	176.93	-61.55
38	14.71	59.117	2.492	6.23	49.84	87.22	31.15	176.93	-117.81
39	11.29	45.372	2.492	6.23	49.84	87.22	31.15	176.93	-131.56
40	22.82	91.709	2.492	6.23	49.84	87.22	31.15	176.93	-85.221
41	39.57	159.02	2.492	6.23	49.84	87.22	31.15	176.93	-17.906
42	21.14	84.957	2.492	6.23	49.84	87.22	31.15	176.93	-91.973
43	8.42	33.838	2.492	6.23	49.84	87.22	31.15	176.93	-143.09
44	20	80.376	2.492	6.23	49.84	87.22	31.15	176.93	-96.554
45	30.85	123.98	2.492	6.23	49.84	87.22	31.15	176.93	-52.95
46	3.85	15.472	2.492	6.23	49.84	87.22	31.15	176.93	-161.46
47	10.43	41.916	2.492	6.23	49.84	87.22	31.15	176.93	-135.01
48	30.14	121.13	2.492	6.23	49.84	87.22	31.15	176.93	-55.803
49	17.4	69.927	2.492	6.23	49.84	87.22	31.15	176.93	-107
50	18	72.338	2.492	6.23	49.84	87.22	31.15	176.93	-104.59
51	3.57	14.347	2.492	6.23	49.84	87.22	31.15	176.93	-162.58
52	0.143	0.5747	2.492	6.23	49.84	87.22	31.15	176.93	-176.36
Total	529.57	2128.2	129.58	323.96	2591.68	4535.44	1619.8	9200.36	-7072.1

4.4.2 Water budgeting of agricultural areas

The major input and output components of this study are rainfall and evapotranspiration respectively. The water demand of the various crops was calculated as the difference between these two parameters. The weekly account of these values gives us an idea of how much water is to be extracted from the available ground water potential.

4.4.2.1 Water budgeting of different crops

The entire cultivable area of 30.66 ha is put under paddy, coconut, fruit trees, arecanut, banana, vegetables, other trees and fodder. The area allocated for each crop varies over year. Evapotranspiration estimated for different crops are shown in Tables 4.7 (a) and 4.7 (b).

Table 4.7 (a) Evapotranspiration (ET_c) of different crops

Std weeks	RF (mm)	ET_o (mm)	ET crop (mm)			
			Paddy	Coconut	Fruit trees	Arecanut
1	0	6.69	7.359	6.021	3.4788	4.35
2	0	6.97	7.667	6.273	3.6244	4.53
3	0	6.54	7.194	5.886	3.4008	4.25
4	53.14	6.98	7.678	6.282	3.6296	4.54
5	13.71	6.47	7.117	5.823	3.3644	4.21
6	6.14	6.34	6.974	5.706	3.2968	4.12
7	9	6.98	7.678	6.282	3.6296	4.54
8	3.29	6.2	6.82	5.58	3.224	4.03
9	0.29	6.26	6.886	5.634	3.2552	4.07
10	0	5.94	6.534	5.346	3.0888	3.86
11	0	6.15	6.765	5.535	3.198	4
12	0	6.24	6.864	5.616	3.2448	4.06
13	0	6.31	6.941	5.679	3.2812	4.1
14	0.86	6.59	7.249	5.931	3.4268	4.28
15	0	5.81	6.391	5.229	3.0212	3.78
16	0	6.01	6.611	5.409	3.1252	3.91
17	0	5.66	6.226	5.094	2.9432	3.68
18	0	8.02	8.822	7.218	4.1704	5.21

19	0	7.6	8.36	6.84	3.952	4.94
20	0	7.19	7.909	6.471	3.7388	4.67
21	7.28	6.78	7.458	6.102	3.5256	4.41
22	54.85	7.8	8.58	7.02	4.056	5.07
23	3.57	7.66	8.426	6.894	3.9832	4.98
24	0	8.17	8.987	7.353	4.2484	5.31
25	0	7.69	8.459	6.921	3.9988	5
26	0.29	7.89	8.679	7.101	4.1028	5.13
27	1.14	7.81	8.591	7.029	4.0612	5.08
28	6.71	8.15	8.965	7.335	4.238	5.3
29	6.71	7.74	8.514	6.966	4.0248	5.03
30	6.28	7.51	8.261	6.759	3.9052	4.88
31	1.43	7.79	8.569	7.011	4.0508	5.06
32	0	7.9	8.69	7.11	4.108	5.14
33	0	8.05	8.855	7.245	4.186	5.23
34	1.28	7.87	8.657	7.083	4.0924	5.12
35	41.71	7.72	8.492	6.948	4.0144	5.02
36	30.85	7.13	7.843	6.417	3.7076	4.63
37	28.71	7.05	7.755	6.345	3.666	4.58
38	14.71	7.04	7.744	6.336	3.6608	4.58
39	11.29	7.3	8.03	6.57	3.796	4.75
40	22.82	7.27	7.997	6.543	3.7804	4.73
41	39.57	6.99	7.689	6.291	3.6348	4.54
42	21.14	6.93	7.623	6.237	3.6036	4.5
43	8.42	7.07	7.777	6.363	3.6764	4.6
44	20	6.77	7.447	6.093	3.5204	4.4
45	30.85	7.05	7.755	6.345	3.666	4.58
46	3.85	6.99	7.689	6.291	3.6348	4.54
47	10.43	7.01	7.711	6.309	3.6452	4.56
48	30.14	6.97	7.667	6.273	3.6244	4.53
49	17.4	7.01	7.711	6.309	3.6452	4.56
50	18	7.03	7.733	6.327	3.6556	4.57
51	3.57	7.29	8.019	6.561	3.7908	4.74
52	0.143	7.37	8.107	6.633	3.8324	4.79

Table 4.7 (b) Evapotranspiration (ET_c) of different crops

Std weeks	RF (mm)	ET_o (mm)	ET crop (mm)			
			Banana	Trees	Fodder	Vegetables
1	0	6.69	5.6865	4.014	5.0175	3.345
2	0	6.97	5.9245	4.182	5.2275	3.485
3	0	6.54	5.559	3.924	4.905	3.27
4	53.14	6.98	5.933	4.188	5.235	3.49
5	13.71	6.47	5.4995	3.882	4.8525	3.235
6	6.14	6.34	5.389	3.804	4.755	3.17
7	9	6.98	5.933	4.188	5.235	3.49
8	3.29	6.2	5.27	3.72	4.65	3.1
9	0.29	6.26	5.321	3.756	4.695	3.13
10	0	5.94	5.049	3.564	4.455	2.97
11	0	6.15	5.2275	3.69	4.6125	3.075
12	0	6.24	5.304	3.744	4.68	3.12
13	0	6.31	5.3635	3.786	4.7325	3.155
14	0.86	6.59	5.6015	3.954	4.9425	3.295
15	0	5.81	4.9385	3.486	4.3575	2.905
16	0	6.01	5.1085	3.606	4.5075	3.005
17	0	5.66	4.811	3.396	4.245	2.83
18	0	8.02	6.817	4.812	6.015	4.01
19	0	7.6	6.46	4.56	5.7	3.8
20	0	7.19	6.1115	4.314	5.3925	3.595
21	7.28	6.78	5.763	4.068	5.085	3.39
22	54.85	7.8	6.63	4.68	5.85	3.9
23	3.57	7.66	6.511	4.596	5.745	3.83
24	0	8.17	6.9445	4.902	6.1275	4.085
25	0	7.69	6.5365	4.614	5.7675	3.845
26	0.29	7.89	6.7065	4.734	5.9175	3.945
27	1.14	7.81	6.6385	4.686	5.8575	3.905
28	6.71	8.15	6.9275	4.89	6.1125	4.075
29	6.71	7.74	6.579	4.644	5.805	3.87
30	6.28	7.51	6.3835	4.506	5.6325	3.755
31	1.43	7.79	6.6215	4.674	5.8425	3.895

32	0	7.9	6.715	4.74	5.925	3.95
33	0	8.05	6.8425	4.83	6.0375	4.025
34	1.28	7.87	6.6895	4.722	5.9025	3.935
35	41.71	7.72	6.562	4.632	5.79	3.86
36	30.85	7.13	6.0605	4.278	5.3475	3.565
37	28.71	7.05	5.9925	4.23	5.2875	3.525
38	14.71	7.04	5.984	4.224	5.28	3.52
39	11.29	7.3	6.205	4.38	5.475	3.65
40	22.82	7.27	6.1795	4.362	5.4525	3.635
41	39.57	6.99	5.9415	4.194	5.2425	3.495
42	21.14	6.93	5.8905	4.158	5.1975	3.465
43	8.42	7.07	6.0095	4.242	5.3025	3.535
44	20	6.77	5.7545	4.062	5.0775	3.385
45	30.85	7.05	5.9925	4.23	5.2875	3.525
46	3.85	6.99	5.9415	4.194	5.2425	3.495
47	10.43	7.01	5.9585	4.206	5.2575	3.505
48	30.14	6.97	5.9245	4.182	5.2275	3.485
49	17.4	7.01	5.9585	4.206	5.2575	3.505
50	18	7.03	5.9755	4.218	5.2725	3.515
51	3.57	7.29	6.1965	4.374	5.4675	3.645
52	0.143	7.37	6.2645	4.422	5.5275	3.685
Total	529.57	367.75	312.59	220.65	275.81	183.86

Irrigation requirement of different crops are given in Table 4.9. From the table, the paddy and coconut are the crops with high water consumption have a surplus rainwater supply for the weeks 4-7, 21-22, 28-30, 35-42, 45 and 47-50. From Table 4.8 it can be seen that there is an annual surplus of 106470.3 m^3 water, which can be effectively harnessed and utilised for irrigation during summer spells.

Table 4.8 Irrigation requirement of different crops

Std. week	Irrigation requirement (m^3)									Surplus /Deficit (m^3)
	Paddy	Coconut	Fruit trees	Arecanut	Banana	Trees	Fodder	Vegetables	Total	
1	698.37	579.22	166.98	23.49	587.25	144.1	47.165	48.5025	2295.078	-2295.08
2	727.6	603.46	173.97	24.46	611.5	150.13	49.139	50.5325	2390.792	-2390.79
3	682.71	566.23	163.24	22.95	573.75	140.87	46.107	47.415	2243.272	-2243.27
4	-4314	-4508	-2376	-262	-6550	-1757	-450.3	-719.93	-20937.2	20937.23
5	-625.7	-758.7	-496.6	-51.3	-1282.5	-352.8	-83.26	-151.89	-3802.75	3802.75
6	79.147	-41.75	-136.5	-10.9	-272.5	-83.86	-13.02	-43.065	-522.448	522.448
7	-125.5	-261.5	-257.8	-24.1	-602.5	-172.8	-35.39	-79.895	-1559.49	1559.485
8	335	220.3	-3.168	3.996	99.9	15.437	12.784	-2.755	681.494	-681.494
9	625.96	514.09	142.33	20.41	510.25	124.43	41.407	41.18	2020.057	-2020.06
10	620.08	514.29	148.26	20.84	521	127.95	41.877	43.065	2037.362	-2037.36
11	642	532.47	153.5	21.6	540	132.47	43.358	44.5875	2109.986	-2109.99
12	651.39	540.26	155.75	21.92	548	134.41	43.992	45.24	2140.962	-2140.96
13	658.7	546.32	157.5	22.14	553.5	135.92	44.486	45.7475	2164.314	-2164.31
14	606.32	487.83	123.21	18.47	461.75	111.07	38.376	35.3075	1882.334	-1882.33
15	606.51	503.03	145.02	20.41	510.25	125.15	40.961	42.1225	1993.454	-1993.45
16	627.38	520.35	150.01	21.11	527.75	129.46	42.371	43.5725	2062.004	-2062
17	590.85	490.04	141.27	19.87	496.75	121.92	39.903	41.035	1941.638	-1941.64
18	837.21	694.37	200.18	28.13	703.25	172.75	56.541	58.145	2750.576	-2750.58
19	793.36	658.01	189.7	26.68	667	163.7	53.58	55.1	2607.13	-2607.13
20	750.56	622.51	179.46	25.22	630.5	154.87	50.69	52.1275	2465.938	-2465.94
21	16.892	-113.3	-180.2	-15.5	-387.5	-115.3	-20.63	-56.405	-871.943	871.943
22	-4391	-4601	-2438	-269	-6725	-1801	-460.6	-738.78	-21424.4	21424.38
23	460.83	319.77	19.834	7.614	190.35	36.833	20.445	3.77	1059.446	-1059.45
24	852.87	707.36	203.92	28.67	716.75	175.98	57.599	59.2325	2802.382	-2802.38
25	802.76	665.8	191.94	27	675	165.64	54.215	55.7525	2638.108	-2638.11
26	796.12	655.22	183.01	26.14	653.5	159.54	52.899	52.9975	2579.427	-2579.43
27	707.1	566.52	140.22	21.28	532	127.3	44.345	40.0925	2178.858	-2178.86
28	214	60.125	-118.7	-7.61	-190.25	-65.34	-5.617	-38.208	-151.6	151.6
29	171.2	24.627	-128.9	-9.07	-226.75	-74.17	-8.507	-41.18	-292.75	292.75
30	188	46.08	-114	-7.56	-189	-63.69	-6.087	-36.613	-182.87	182.87
31	677.49	536.89	125.8	19.6	490	116.46	41.478	35.7425	2043.461	-2043.46
32	824.68	683.98	197.18	27.76	694	170.17	55.695	57.275	2710.74	-2710.74
33	840.34	696.97	200.93	28.24	706	173.4	56.753	58.3625	2760.996	-2761

34	700.08	558.25	135	20.74	518.5	123.57	43.452	38.4975	2138.09	-2138.09
35	-3152	-3344	-1809	-198	-4950	-1331	-337.6	-548.83	-15670.4	15670.43
36	-2183	-2350	-1303	-142	-3550	-953.9	-239.7	-395.63	-11117.2	11117.23
37	-1989	-2152	-1202	-130	-3250	-878.8	-220.2	-365.18	-10187.2	10187.18
38	-661.1	-805.6	-530.4	-54.7	-1367.5	-376.4	-88.64	-162.26	-4046.6	4046.6
39	-309.4	-454.1	-359.7	-35.3	-882.5	-248.1	-54.66	-110.78	-2454.54	2454.54
40	-1407	-1566	-913.9	-97.7	-2442.5	-662.6	-163.3	-278.18	-7531.18	7531.18
41	-3026	-3201	-1725	-189	-4725	-1270	-322.7	-523.09	-14981.8	14981.79
42	-1283	-1434	-841.7	-89.9	-2247.5	-609.7	-149.9	-256.29	-6911.99	6911.99
43	-61.02	-197.9	-227.7	-20.6	-515	-150	-29.3	-70.833	-1272.35	1272.353
44	-1191	-1338	-791	-84.2	-2105	-572.2	-140.3	-240.92	-6462.62	6462.62
45	-2192	-2357	-1305	-142	-3550	-955.7	-240.3	-396.21	-11138.2	11138.21
46	364.32	234.82	-10.33	3.726	93.15	12.35	13.09	-5.1475	705.9785	-705.979
47	-258	-396.4	-325.7	-31.7	-792.5	-223.4	-48.62	-100.41	-2176.73	2176.73
48	-2133	-2296	-1273	-138	-3450	-931.9	-234.2	-386.5	-10842.6	10842.6
49	-919.5	-1067	-660.2	-69.3	-1732.5	-473.7	-114.1	-201.48	-5237.78	5237.78
50	-974.3	-1123	-688.5	-72.5	-1812.5	-494.8	-119.6	-210.03	-5495.23	5495.23
51	422.21	287.73	10.598	6.318	157.95	28.864	17.837	1.0875	932.5945	-932.595
52	755.78	624.34	177.09	25.09	627.25	153.62	50.614	51.359	2465.143	-2465.14
Total	-11867	-19105	-16240	-1569	-39201.7	-11090	-2385	-5012.6	-106470	106470.3

4.5 Design of roof top water harvesting structures

The advantage of roof top water harvesting systems is that they make use of the natural water cycle in a sustainable way. By bringing water closer to the users, they minimize the amount of energy needed to transport it. Also the rainwater collected from the roof is free from contamination except for some dust and other silt particles which can be filtered and the water can then be used directly. The design procedure of each component of the roof top water harvesting system for Academic block is given in Appendix IV. Rainwater harvesting system for subsurface recharge was designed in such a way that the rate of runoff due to rain fall is equal to the rate of movement of water through the soil avoiding long term stagnation and loss of water by surface runoff.

4.6 Design of percolation pond

Rainwater management in agricultural land consists of the following steps.

1. Collection of part of the rainfall in the crop land until such time and extent as will not be harmful to the crop.
2. Directing the excess water into a dugout pond. The stored water can be utilised for irrigation in the adjacent land during dry spells or can be allowed to percolate and rejuvenate the ground water.

From the slope maps two sites for water harvesting ponds were identified and the sites recommended are

Mango orchard

Near to the farm office

4.7 Recharging of wells in agricultural land

The excess water can be directed to open wells through a filtering arrangement. Filters ensure the prevention of clogging, contamination and silting of wells. The filtering tanks can be divided in to two sections using perforated slabs. Each portion should be filled with pebbles and brick jelly and connected to the wall through a 15 cm PVC pipe. The reverse flow of rainwater to the filtering tank can be directed through the available filed channels in the farm.

Chapter 5

SUMMARY AND CONCLUSIONS

Vagaries of rainfall, fast depletion of water resources and increasing water demands emphasize the need for implementation of efficient water resource planning. The three essential keys for any successful water resource development project are proper resource assessment, demand estimation and efficient supply management. Water budgeting gives the best solution for this approach.

The KCAET campus depends on groundwater for its various agricultural and non-agricultural uses. Drinking water and other demands are now being met from the tube well and open well in the campus. The campus covers an area of 40.07 ha and the buildings occupy an area 9.44 ha. Almost all the open wells are dry and the aquifers are being tapped heavily to satisfy the water requirements during the summer.

Climatic data of 1 year (October 2010 - September 2011) was analysed to find the coefficient of variation. The mean annual rainfall of Tavanur is 529.57 mm. The contribution of South West monsoon, North East monsoon and summer and winter showers are 66.67, 16.16, 15.53, 1.54 percent respectively. Analysis of annual and monthly rainfall data is inadequate to evaluate the moisture availability at various stages of crop growth and the water needs over a short period. Hence rainfall data was analysed on a weekly basis.

The contour map of the study area was prepared and with the help of that position for two farm ponds were identified.

An account of the replenishments and depletions of water for the entire study area was done. The total demand for water of office buildings in a year is about 4080 m^3 and water harvested from roof tops covers 11824.22 m^3. This provides a surplus of 7744 m^3. This shows that the water harvested from roof top is 2.8 times more than the demand. From the analysis of weekly deficit/surplus it is seen that the standard weeks 4-7, 21-23, 28-30 and 35-51 shows surplus. This surplus water which comes to 9506.96 m^3 is sufficient to meet the total water deficit for the remaining weeks.

The roof water harvesting potential of the residential building is calculated to be around 1609.78 m^3 and the water needed to meet the various demand is 4031.56 m^3.The annual demand for drinking and cooking come to only 198.74 m^3 while the roof top water harvesting potential is 1609.78 m^3. Hence there is an option for storing and using the rain water for drinking and cooking throughout the year. This will end the dependability on well water supply to meet these demands. The remaining 1411.04 m^3 can be used up for other purposes when acute shortages arise.

The potential of roof top water harvested from the hostels comes to only 2128.2 m^3 while the total demand is of the order of 9200.36 m^3. The drinking and cooking demand together is around 453.54 m^3. The most feasible solution is to store this excess water to meet the drinking and cooking demands during the lean weeks so that the demand on well water supply can be reduced.

The paddy and coconut are the crops with high water consumption have a surplus rainwater supply for the weeks 4-7, 21-22, 28-30, 35-42, 45 and 47-50. Here the evapotranspiration needs are fully met by the rainfall. This water can harvest and made use of in the following dry weeks.

By considering the water requirement of all crops, we can see that there is a surplus of water except in the standard weeks of 1-3, 8-20, 23-27, 31-34, 46 and 51-52. The water requirement on annual basis shows a surplus of 106470.3 m^3. This surplus water can be used for other purposes.

The design procedure for each component of the roof top water harvesting system was done. By bringing water closer to the users, they minimize the amount of energy needed to transport it. Also the rainwater collected from the roof is free from contamination except for some dust and other silt particles which can be filtered and the water can then be used directly. Rainwater harvesting system for subsurface recharge was designed in such a way that the rate of runoff due to rain fall is equal to the rate of movement of water through the soil avoiding long term stagnation and loss of water by surface runoff.

The design of proposed pond was done. The stored water can be utilized for irrigation in the adjacent lands during dry spells or can be allowed to percolate and rejuvenate the ground water. The excess water can be directed to abandoned open wells through the filtering arrangement. Filters ensure the prevention of clogging, contamination and silting of wells.

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APPENDIX I

Details of buildings in KCAET campus

Sl. No.	Building	Roof area (m^2)	Lawn area (m^2)	No. of persons
I	**Office buildings**			
1	Administrative block (new)	3568	520	38
2	Administrative block (old)	442	0	0
3	KVK	650	190	28
4	PFDC	1426	0	5
5	Auditorium building	301	0	0
6	Library	824	0	5
7	Engineering division	400	0	11
8	Veterinary hospital	440	0	1
9	Work shop (new)	762	0	4
10	Carpentry shop	236	0	1
11	Smithy shop	140	0	1
12	Ceramic work shop	640	0	13
13	Training complex	425	0	0
14	Trainees hostel	1066	0	0
15	KVK trainees hostel	393	0	0
16	Guest house (old)	126	0	0
17	Canteen	198	0	5
18	PHE Lab	1670	0	0
19	Science lab	492	0	0
20	Farm machinery lab	1575	0	0
21	Soil and water engineering lab	1575	0	0
22	Hydraulics lab	1575	0	0
23	Electrical engineering lab	1575	0	0
24	Strength of materials lab and agricultural processing machinery lab	1575	0	0
25	Steam engine lab	1575	0	0

26	Farm machinery yard-1	445	0	1
27	Farm machinery yard-2	942	0	0
28	Cattle shed (new)	503	0	2
29	Cattle shed (old)	292	0	2
30	Store cum farm office	240	0	25
31	Farm store	90	0	2
II	**Hostels**			
32	Ladies hostel (Greeshma)	399	0	26
33	Ladies hostel (new)	1662	0	102
34	Men's hostel	2667	0	50
III	**Residential buildings**			
35	D –type quarters	1028	0	26
36	Type II quarters	290	0	13
37	Type III quarters	393	0	24
38	Type IV quarters	286	0	3
39	Type V quarters	608	0	2
40	Type VI quarters	327	0	0
41	KVK quarters	533	0	10

APPENDIX II

Land use pattern of KCAET campus

Area code	Land use	Area (ha)
L1	Uncultivated area	9.12
L2	Cashew &acasia	0.15
L3	Cashew, acasia & coconut	0.05
L4	Cashew, mango & jackfruit	1.57
L5	Coconut	1.69
L6	Miscellaneous trees	0.29
L7	Arecanut	0.42
L8	Miscellaneous trees & shrubs	0.32
L9	Acasia & mango	0.39
L10	Miscellaneous trees	2.39
L11	Cashew	0.22
L12	Coconut & nutmeg	0.19
L13	Coconut	0.21
L14	Cashew	0.83
L15	Coconut & nursery	0.27
L16	Cashew & coconut	0.37
L17	Cashew	0.22
L18	Miscellaneous trees	0.62
L19	Uncultivated area	0.29
L20	Plantation crops & coconut	0.02
L21	Suppotta	0.01
L22	Coconut	0.24
L23	Jackfruit, pepper, mango & coconut	0.19
L24	Arecanut	0.12
L25	Coconut	0.14
L26	Coconut	0.35
L27	Miscellaneous trees & pepper	0.22
L28	Coconut & trees	0.32

L29	Coconut	4.13
L30	Paddy	1.05
L31	Plantation crops & coconut	0.08
L32	Vegetables & tapioca	1.35
L33	Paddy	8.44
L34	Coconut & plantation	0.17
L35	Coconut & plantation	0.17
L36	Miscellaneous trees	0.18
L37	Coconut	0.39
L38	Mango	1.18
L39	Coconut	1.17

APPENDIX III

Meteorological data

Std. weeks	T_{max} (^oC)	T_{min} (^oC)	RH (%)	n/N	U_2 (m/s)	R_s (W/m^2)
1	27.5	25.6	93.59	0.54	1.52	417.01
2	27.25	26.16	90.53	0.34	1.48	417.01
3	25.9	24.91	93.46	0.44	1.58	417.01
4	26.21	25.35	92.9	0.26	1.62	417.01
5	27.02	26.07	90.81	0.29	1.49	385.8
6	26.58	25.68	90.86	0.26	1.49	385.8
7	27.12	26.01	90.73	0.35	1.63	385.8
8	26.44	25.54	89.82	0.4	1.67	385.8
9	26.52	25.59	85.68	0.56	1.47	385.8
10	26.49	25.43	83.9	0.62	1.46	365.94
11	26.3	25.11	82.9	0.36	1.8	365.94
12	26.66	25.48	76.11	0.59	2.06	365.94
13	30.39	29.09	79.2	0.55	2.32	365.94
14	27.13	25.98	77.38	0.48	2.43	374.46
15	26.46	25.87	93.58	0.66	1.72	374.46
16	27.18	26.16	91.49	0.37	2.14	374.46
17	26.21	25.74	91.15	0.63	2.13	374.46
18	27.55	26.3	64.53	0.27	2.62	402.82
19	27.36	25.88	65.95	0.44	2.16	402.82
20	26.15	25.19	70.18	0.49	2.35	402.82
21	27.46	26.34	81.39	0.55	2.53	402.82
22	28.49	26.99	74.68	0.57	2.35	434.02
23	28.69	27.59	80.76	0.44	2.04	434.02
24	29.4	28.18	70.69	0.63	2.35	434.02
25	28.88	28.2	75.79	0.74	2.65	434.02
26	29.7	28.67	77.36	0.6	2.13	434.02
27	28.96	27.86	83.1	0.29	2.51	445.37
28	29.65	28.52	75.64	0.61	1.93	445.37

29	29.13	27.97	78.32	0.72	2.42	445.37
30	28.74	27.8	83.38	0.74	2.12	445.37
31	29.2	28.4	80.46	0.63	2.18	439.7
32	29.5	28.47	77.57	0.68	2.26	439.7
33	30.64	28.99	78.18	0.69	2.39	439.7
34	29.52	28.94	79.26	0.65	2.27	439.7
35	27.52	25.51	80.36	0.22	2.04	439.7
36	26.27	25.76	94.6	0.11	1.47	434.03
37	26.57	25.57	93.67	0.1	1.74	434.03
38	27.36	26.04	90	0.25	2.45	434.03
39	27.11	26.14	86.1	0.26	2.21	434.03
40	26.68	25.74	89.36	0.23	1.82	434.03
41	26.13	25.28	91.23	0.09	2.16	434.03
42	25.49	24.56	93.43	0.05	2.07	434.03
43	24.97	24.84	93.3	0.06	1.76	434.03
44	23.94	24	96	0.08	1.84	439.7
45	26.09	25.23	93.92	0.05	2	439.7
46	26.06	25.83	90.94	0.24	2.15	439.7
47	26.33	25.81	91.64	0.21	2.09	439.7
48	25.83	24.95	95.86	0.05	1.95	439.7
49	26.46	25.42	93.11	0.11	1.63	434.03
50	26.27	25.42	92.91	0.06	1.89	434.03
51	26.52	25.89	90.13	0.07	1.58	434.03
52	27.05	26.73	87.82	0.06	2.26	434.03

T_{max} - Maximum temperature

T_{min} - Minimum temperature

RH - Relative humidity

U_2 - Wind speed

n - Number of bright sunshine hours

R_s - Solar radiation

N - Possible day length

APPENDIX IV

Design of roof top water harvesting system components for Academic block

Down pipe

Total roof area = 3568 m^2

Runoff coefficient = 0.85

Intensity of rainfall = 1.7×10^{-5} m/s

Maximum discharge, Q = 0.052 m^3/s

Diameter of down pipe,

$$d_{down} = [(Q \times f^{0.5})/1.74]^{0.4}$$

f = 0.009 for asbestos cement pipes and

f = 0.004 for PVC pipes

$d_{asbestos}$ = 10 cm

d_{pvc} = 8 cm

Diversion pipe to detention basin

Diameter of diversion pipe,

$$d_{div} = [(Q \times n_{pvc})/(0.311 \times S^{0.5})]^{0.37}$$

n_{pvc} = 0.009

S = 0.015

d_{div} = 20 cm

Detention basin

Considering the depth of basin as 1 m,

$T = (0.03 \times 0.016 \times 1) / (1.8-1) \times 4 \times (0.001)^2$

$= 150$ sec

The time required for the particle to settle in a 1 m deep tank is 150 sec. Taking the length of the basin as 1.5 times the width,

$A = L^2/1.5$

$V = (0.052 \times 1.5)/ L^2$

Length of basin = Maximum flow velocity x Time for settling

L = V x 150 = 2.3 m

B = 1.53 m

D = 1 m

Filtration tank

Rate of filtration for the media of depth 1 m was taken as 200 l/min-m^2

Area of the tank = Maximum discharge / Rate of filtration

= 3.12/0.2 = 15.6 m^2

= L x B = L x (L/1.5)

L = 4.8 m; B = 3.2 m D = 1 m

Storage tank

Maximum volume of water collected from roof top in a week = Runoff coefficient x Roof area x Maximum depth of rainfall

V = 0.85 x 3568 x0.053 = 160.73 m^3

Assuming depth of the tank as 2 m and length as 1.5 times the breadth

A = 160.73/ 2 = 80.36 m^2

L = 10.97 m; B = 7.32 m; D = 2 m

ABSTRACT

Water plays the major role in securing all possible forms of life on earth. Water harvesting has become the order of the day in most parts of our world on account of the vagaries of monsoon, mismanagement of irrigation water and over exploitation of surface and subterranean water storage for domestic, agricultural and industrial needs. The primary objective of any water harvesting system is to arrive at optimal water budgeting in order to sustain crop production and to provide water reserves for domestic and industrial usage. The case study taken up in KCAET campus encompasses a systematic procedure for exploring rain water harvesting potential towards water budgeting for multiple water usage.

The study has covered overhead, surface and subterranean water harvesting strategies with the principal objective of creating an orderly water budgeting schedule for judicious usage of water for agricultural, domestic and laboratory water needs. Designs related to roof top water harvesting, farm ponds for supplemental irrigation and percolation ponds for ground water recharge have been made based on an extensive rainfall analysis. Contour map of the area was prepared and the sites for the farm ponds were identified.

The annual roof top water harvesting potential of the office, residential buildings and hostels were determined. The drinking water needs of KCAET campus can be met completely from the harvested water. The remaining roof water can be used to meet the sanitary, laboratory and miscellaneous demands in the buildings. Similarly, excess water stored in the crop fields after meeting their requirements can be used for irrigation during the dry spells. The water collected can also be used for recharging the groundwater.