IMPACT OF URBANISATION ON WATER RESOURCES & OPPORTUNITY OF RWH STRUCTURE IN NAINITAL

Major Project Dissertation

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DECLARATION

This is to certify that the work that forms the basis of this project "IMPACT OF URBANISATION ON WATER RESOURCES & OPPORTUNITY OF RWH STRCUTURES IN NAINITAL" is an original work carried out by me and has not been submitted anywhere else for the award of any degree.

I certify that all sources of information and data are fully acknowledged in the project Dissertation.

PALASH RAGHAVA

Date: 29th May 2020

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Abstract

This study is aimed at to understanding the relationship between urbanization growth and surface run-off generation, thus to explore the scope of rainwaterharvesting potential in the study area of Nainital. The rapid urbanization due to increased tourists' inflow, population, growth in infrastructure facilities has made the town susceptible to the risks of change in climatic conditions. The rapid urbanization has created a threat to water security in Himalayan towns. The current challenge in this century is to control the shortage of water through Rainwater Harvesting Structure and making it sustainable as well as viable for the end-users. The study projects combine the approach of Remote Sensing technology and Geospatial techniques to understand the change in Land Use/Land Cover pattern of the tourist town Nainital between the years 1990 to 2020 over four decades. The SCS-CN method has been used to generate surface run-off from the rainfall data available between 1990-2010. The surface run-off has been generated according to the Land Use/ Land Cover andsoil group for the Nainital town. The rainwater harvesting potential for different scales has been calculated season-wise and compared with lake supply data for those seasons to estimate the volume of water that can be stored using rainwater harvesting (RWH) structures in the built-up area as well as to reduce the supply from the lake. OneRWH Structure has been designed for a commercial property, estimating the volume of water that can be stored according to the area of the rooftop.

Key-Words: **Rapid Urbanization, Himalayan towns, Water Security, Remote Sensing, Surface Run-off, Rainwater Harvesting Structure**

1. Introduction

Rapid Urbanisation is one of the major driving factors for global climate change in the recent years (kumar and Pushplata, 2015). The basic definition of urbanization is increasing in the number of people living in town and cities, mainly migrated from rural areas to urban areas which have resulted in growth in the urban population size as well as an increment in the urban area. As per a recent estimate 55% of the world's population (4.2 billion) lives in the urban area and this figure is expected to increase to 68% by 2050 (UN DESA, year?). India, China & Nigeria will account for 35% of the expected growth of the world's population between 2018 and 2050. India will add 416 million urban dwellers whereas China 255 million and Nigeria will account for 189 million by 2050. In India, urbanization is one of the important drivers of economic development. The economic growth holds a direct relation with urbanization, as the rate of the economy is affected by the urbanization. The increase in the urban area, the share of national income arisen from the urban sector also increases. The important geographical units in the country which experience the urban population growth since the past are north-west, the Gangetic plains, and southern India.

Urbanisation in Himalayan Region

In the hilly regions of Himalaya, urbanization has been largely unsystematic and unplanned and rapid increase in the tourism have been major driver in hills. The urbanization has two key aspects-, on one hand rapid increase in urban areas in high mountains is creating opportunities for employment, socio-economic services and infrastructure developments. However, on the other hand, it has disturbed the critical ecosystem services like water security. Rapid and unplanned urbanization has unsettled the hydrological system of Himalayan watersheds and reduced groundwater recharge possibilities as well as decreased the water availability of water for drinking, household purposes, increased risks of natural calamities both in urban as well as in peri-urban settlements. In the recent years, the least accessible areas in Himalaya are being converted in the urbanized sector due to the road network, tourism, and economic globalization(Tiwari, Joshi, & Joshi, 2016). In the hill towns, the influx of migrants, tourists coupled with the growth of population has created a stress on the supply of clean, adequate water, sanitation, solid waste management (Tiwari et al., 2018).

Mountains have seen urban growth as a result of physical, socio-economic drivers e.g. many hill cities have developed by the encroachment of nearby hills, for example, Nainital in Uttarakhand which witnessed expansion on its hillside in the 1970s (Singh et al.,2020) Nainital is a hill town widely famous for its tourist attraction such as Naini Lake, Bhimtal, Snow view point, Tiffin top, Naina Peak to name few. The Nainital district of Kumaun hills has a tropical, subtropical, temperate, and alpine zone in its territory. It is covered with Sal, Pine, Oaks, Kaphal till 1828 meters and Deodar, Surai, etc. at a higher elevation. The town has a wide variety of wildlife around itself. The dense forests are the natural home of barking deer, black bears, leopards, and birds such as Himalayan Whistling Thrush, Red-Billed Blue Magpie and more can be spotted. During the 1970s, the urbanization increased by the encroachment on its steep slopes with population density increasing from 2111 to 4177 persons/km^2, with a geographical area of 11.73 km^2. Nainital witnesses a floating population of 1,50,000 during the peak tourist season in the summers (Tiwari & Joshi, 2016). In the past 4decades, the town has been under the phase of rapid urbanization and different type of anthropogenic activities such as road construction, hotels, parking, and recreational sites made the town landslides prone, increased its susceptibility to rock falls, creeping (Tiwari, 2014). Naini lake apart from tourist attraction is the main source of drinking water for the town, other sources comprise of various springs such as Pardadhara, Sipahi Dhara, etc.

Impact of Land Use Land Cover change dynamics

In this study, land use/land cover change dynamics have been studied from 1990-2020. Land Use/ Land Covers depicts the various kind of different materials of Earth's surface like water, forest, concrete for the built-up area. The Remote Sensing- GIS-based tool for mapping of Land Use/ Land Cover provides the pertinent data for many aspects such as global climate change and the effects of various types of Land Use/ Land Cover patterns or classes. The study of Land Use/Land Cover change over the period is important to map the human activity directly related to land and change in a pattern according to different classes Land Use/ Land Cover Classification with help of Remote Sensing & GIS tool in ERDAS Imagine or ArcGIS. The change detection has been used in this study to capture the difference in classes in a period of varying time. (Rawat J et.al, 2004) in their study have undertaken the Nainital for their research work, performed Land Use/ Land Cover Classification using Remote Sensing & GIS application for the year 1990 and 2010. In the previous study, the authors have mapped the change detection in Land Use/Land Cover attributes and finds out that the urbanization has increased as well as the GIS tool is useful to detect the change in Land Use pattern. The previous studies lacked in identifying the classes contributing to each other during the change detection process in terms of area (Km^2).

Rainfall Trend Analysis

The Rainfall trend analysis is important to understand the rainfall pattern of the study area and to predict the extreme rainfall events, seasonal trend analysis, surface runoff, RWH potential etc. Rainwater Harvesting Structures are a sustainable method to utilize the water resource. As, in the current scenario, the world is facing a crisis in the availability of fresh water to drink as well as cooking and households. In present days, the hill towns which have been developed as tourist hotspots, are underwater stress zones. As the number of tourist inflow is increasing demanding and creating opportunities for more employment, infrastructure developments like Hotels, Restaurants, Recreational places, etc. have made these towns water scarce. Rainwater Harvesting can be a potential way to cater to the increased water demand in the hill towns also. Nainital is a hill town in Kumaun region, a lake town and tourist hotspot where tourist influx is in huge numbers during peak season which creates stress on Lake for water supply in different wards to meet the demands of town's population as well as of tourists. Rainwater Harvesting can make the town sustainable in its way and will help in maintaining the Lake water level during the peak season and the rest of the year.

The study aims to generate Land Use/Land Cover Classification to understand the change detection in all classes and to develop Change Detection Matrix to get detailed insight in terms of statistics. The aims to predict thesurface -run off using conventional methods, land use/land cover statistics and rainfall data. The last objective of the study is to identify the RWH potential and to design a pilot project for a rooftop in the study area.

2. Literature Review

2.1. Impact of Urbanisation

kumar and Pushplata (2015) their study mentioned the reasons for the pressure of development in the Himalayan regions during the last few decades. The Himalayan regions are converted into hill towns as preferred tourist locations, accounting main economy generators for the hilly region population. In their study, they have mentioned about the various issues or problems faced by the hill towns due to high urbanization and increased development. The population increased due to migration from the nearby regions, heavy tourist inflow lead to constructions of the multi-storeyed building for all purposes. The study has been conducted on existing building bye-laws/ regulations for residential buildings such as plot size, number of stories. They have also mentioned the regulations for rainwater harvesting structures though, it is not enforced effectively as RWH's aren't implemented in a majority of buildings. The study also mentions developing a suitable method to modify the existing laws or regulations for hill towns based on the analytical study of different approaches to make them function efficiently.

Tiwari and Joshi (2016)their article has analysed the impacts of rapid urbanization socio-ecological systems of Himalayan towns. The authors have mentioned how rapid urban growth has made these towns prone to natural risks with a change in climatic conditions. The town of Nainital has been talked about in this article like how the population density has increased with time, it hosts the tourist population of 1,50,000 per year in the peak season during summers and the period of massive urbanization. The article mentions the incremental growth of the built-up area on steep slopes making it vulnerable to landslides. The rainfall pattern has also changed as the incidence of high rainfall and droughts are rising to create a serious threat to the ecosystem. The entire Uttarakhand has been facing severe drought conditions since 2015. The entire north-western population of the town is on the landslide's debris accumulated through successive landslides in past. The authors have recommended the mapping of large-scale risk zone on parameters of livelihood, demography, infrastructure, etc. They have stressed developing an adaptation of urban land use policy, a framework of water resource conservation, and prohibition of anthropogenic activities in the recharge zone of Naini Lake.

Tiwari P et.al.,(2018)in their study identified the pattern of increasing urbanization and drivers. The study mentions the overall process of urbanization, its impact on both socio-economic and environmental across the Himalayan states. The Himalayan region has experienced rapid growth in urbanization due to improved road connectivity, tourism development, as these two are a major contributor. The study mentions the unplanned urbanization in form of urban settlements especially in tectonically alive and ecologically fragile lesser Himalayan ranges has resulted in depletion of natural resources such as forests, water as well as increasing the risk of natural calamity like flash floods, landslides in the urban and its surroundings. The authors have identified land use as the major reason driving the transformation of the natural landscape and it has affected the ecosystem services in the region. Also, the agricultural land in the region has been encroached due to the process of rapid urbanization and the vast development of infrastructure, services, and increasing economic activities. The study has identified the gap in the way as no climate change adaptation plan has been enforced in any of the Himalayan cities by the State Governments. Also, there is no proper risk assessment of natural calamities like flash floods, cloudbursts events, and other natural disasters. In their study, the authors have suggested climate change vulnerability assessment and mapping of Himalayan towns, risk zone mapping, and implementation of the Urban Land Use policy

2.2. Remote Sensing & GIS

Chakravarti and Jain (2014)illustrated an integrated approach of remote sensing and GIS for assessment of land use/land cover aspects of a tourist town located in Uttarakhand state i.e. Nainital. For GIS-based assessment, they used Landsat TM of 1990 & Landsat TM of 2010 acquired from USGS Earth Explorer to quantify the Land Use/ Land Cover Changes in the town from 1990 to 2010 for two decades. ERDAS imagine 9.3 software has been used for the study with Supervised Classification methodology. In the study area, they classified features into five classes which are built-up area, vegetation, agricultural land, water bodies, and sand bar. The result of the study indicated that the built-up area in the town has increased over two decades while other classes like vegetation, agricultural land have decreased.

Rawat et.al.,(2004)in their study adopted an integrated approach of remote sensing and GIS for assessing the Land Use/ Land Cover dynamics of Nainital town. The datasets used for this assessment were for the years 1990 and 2010. The methodology adopted in this study for Land Use/ Land Cover was supervised classification in ARC GIS 9.3 using the Maximum Likelihood Technique. The results gave the information about an increment of Built-Up and Open Spaces between 1990 & 2020 whereas forest cover, vegetation has decreased. The study concluded that Nainital is witnessing expansion in the Urban nuclear settlement.

2.3. Rainfall Simulation and Trend Analysis

Bhagat (2016)mentions that Soil Conservation Service-Curve Number (SCS-CN) practiced by engineers, watershed managers as run-off estimation model. The SCS-CN calculates surface-run off volume for a given rainfall from watershed like agriculture, urban , forests etc. In this study, LULC classification has been performed for Lower Mahi Basin and then, SCS-CN number has been calculated for different type of Land Cover classes and hydrological soil group. The study could have been more intensive, if the author would have calculated surface-runoff volume to show the relevance of SCS-CN method in predicting surface run-off volume.

Shuster*et al*.,(2008)discussed that urban catchments require an assessment of hydrologic characteristics of the previous- impervious system. In this study, Rainfall simulation has been used to observe surface runoff by creating an impervious layer using boxes connected in series to produce different arrangements of impervious and pervious surfaces having different outlets. After the simulation run, infiltration rates declined due to reduced opportunities for infiltration. Thus, rainfall simulation is a better way to understand aspects of urban hydrology and models.

John and Brema (2018) in their study have performed Rainfall Trend Analysis using the Mann-Kendall Trend Test for the Vamanapuram River Basin. The study mentions that the rainfall trend analysis helps to understand the rainfall pattern of the study area for the study period. The study aims to explore a very vital climatic element that is, rainfall. The study has emphasized the fact that Urbanisation leads to climate change with the change in Land Use dynamics which affects the change in the run-off. The authors have clearly stated that the amount of rainfall received is very much relevant to the amount of water available to meet the demands of household supply, agricultural, industrial, and power generation. The Mann-Kendall Test analysis of monthly and annual rainfall will help in stormwater management and flood in the catchment area of the study. The Mann-Kendall Trend Analysis is of a time series is a statistical method used to study the spatial as well as a temporal variation of hydroclimatic series. The trend analysis is useful to understand the rainfall pattern in different seasons and to anticipate floods like situation.

2.4. RWH

Mishra *et al.*, (2013)mentions in their study that basic amenity is going to face a serious issue as "water crises" in the upcoming time. The exploitation rate of water is more than the rate of recharge and conservation. This study gave the estimate of demand in the rural area that is, water requirement in a rural area is predicted to be 29 billion cubic meters in 2050 in comparison to the present requirement of 10 billion cubic meters. The authors have mentioned factors creating water crisis in India such as improper use of treated water, lack of awareness in the community related to groundwater, no proper mechanism of groundwater recharge, overexploitation, etc. There are different types of agro-climatic zones of India and water harvesting techniques are different depending upon zones and purpose as it is a challenging task to suggest a single type of rainwater harvesting structure for water sustainability. The study talks about the different types of benefits such as to public as it will cut down the cost of water supply infrastructure costs, reduces the surface runoff, control the flood in low lying areas, etc. Many Indian states have taken the step to implement rainwater harvesting to create efficient supply throughout the year and NGOs are taking responsibility to create awareness about Rainwater Harvesting Structures.

Singh *et al.*, (2011) mentions that the biggest challenge of the current era is water scarcity and to overcome it. Rainwater Harvesting has been identified as an alternative way to tackle the problem of water scarcity as it’s sustainable and cost effective technology. The paper has clearly states that harvesting rainwater is to optimise the rainfall i.e. to store it without allowing it to convert into runoff. Groundwater recharge is declined due to increasing built-up areas and concreting surface of open areas. The water supply infrastructure faces problems to cope up with the demand specially during summer season. Over extraction of groundwater has depleted the groundwater table and has dried up many borewells. Rainwater Harvesting is a eco-friendly method as an alternative supply of water. Either the rainwater can be used for groundwater recharge through injection wells or storing in tanks, vessels for household purposes and after treatment process can be used for drinking. The study area is Kutlehar in Shiwalik hills and the climatic year has been divided into three seasons i.e. hot season from March-May, rainy season from June-September and cold season from October to February. The study has shown that the water supply has reduced in the dry seasons and water sources fails to cope up the demand in the Shiwalik hills. The water holding capacity of the soil in the study area is low , susceptible to soil erosion, landslides due to water. In the study, the authors have calculated the volume of water that can be stored from the rooftop and demand in terms of LPCD. The study has shown that rooftop harvesting can be done to meet the water demand for drinking as well as cooking purposes.

2.5. Objective

i. To understand the Land Use Land Cover Dynamics of Nainital Town using GIS techniques.
ii. Estimation of Surface Runoff according to Land Use & Rainfall Analysis.
iii. To identify Rainwater harvesting potential as well as policy compliance in Nainital town.

3. Materials & Methodology

3.1. Study Area

Nainital Town (Fig.1) in Uttarakhand extends between 29°24'19"N to 29°21'42"N latitudes and 79°25'46"E 79°28'25"E longitudes. This town is a popular hill station encompassing an area of 12.19 km^2. Nainital is located in a valley having a lake with mean depth of 18.55m(Rawat, Biswas and Kumar, 2004). Nainital is the tourists destination for people and main centre of attraction is the Naini Lake situated in middle of the town. Naini Lake is the main source of water supply in the town.

Fig.3.1. Satellite image of Nainital Town. Source: Google Earth

3.2. Land Use/Land Cover

To obtain the Land Use / Land Cover classification, ERDAS Imagine software will be applied. The identified Land Use and Land Cover for this study will be (i) Built-Up land (ii) Vegetation cover (iii) Water Body (iv) Open Space (v) Agricultural Land (Rawat, Biswas and Kumar, 2004).

Table 1. Datasets for Land Use/Land Cover Classification.

Dataset	**Date & Year**	**Resolution**
Landsat 4-5	4th April, 1990	30m
Landsat 4-5 Level 1	27th January 2000	30m
Landsat 7	12th January 2010	30m
Landsat 8	18th January 2020	30m

3.3. Estimation of Surface Runoff according to Land Use & RainfallAnalysis

- **SCS-CN Method**

The SCS-CN method have been used to estimate the surface runoff generated in accordance to Land Use statistics and daily rainfall data for the years 1990, 2000, 2010. The validation of the value obtained from the empirical formula (SCS-CN method) will be done at later stage with lab experiment(Bhagat, 2016). For use in Indian conditions, the daily runoff has been calculates using following formula:

$$Q = \frac{(P - 0.1S)^2}{P + 0.9S} \qquad \text{for } P > 0.1S$$

$$S = \frac{25400}{CN} - 254$$

Table.2 Antecedent Moisture Conditions (AMC) for Determining the CN Value

Total Rainfall in previous 5 days		
AMC	**Dormant Season**	**Growing Season**
I	**<13mm**	**<36mm**
II	**13 mm to 28 mm**	**36mm to 53mm**
III	**> 28mm**	**> 53mm**

- Valid for Black soils under AMC of Type II and III. Soil is Group C (Moderately High Runoff potential).

Table.3 Runoff Curve Numbers [CNII] for Hydrologic Soil Cover (Under AMC

Land Use	CN II (Soil Group C)
Lake	**100**
Built Up	**91**
Vegetation	**58**
Open	**60**

- The **Rationale formula** has been used also to estimate the surface runoff.

$$Q = \frac{1}{360} C.\ i.\ A$$

where:

Q =Peak rate of runoff, m 3/sec
i =Intensity of rainfall, mm/hour
C =runoff coefficient
A =Area of the catchment, ha

Table.4 Runoff Coefficient

Land Use	**Run off Coefficient C**
Built Up	0.9
Agriculture	0.5
Open Lands	0.6
Moist Deciduous Forest	0.15
Evergreen to Semi evergreen forest	0.1
Forest Plantation	0.6
Agriculture Plantation	0.5
Dry Deciduous Forest	0.15

Source: Estimation of SCS-CN N.K Bhagat (SCS-’, 4(4), pp. 61–63).

The Land Use value of different classes (Area) has been used to calculate the runoff.

Mann Kendall Trend Test

The Mann Kendall Test or “M-K Test” is used to do the analysis of data collected over time for having varying trends i.e. increasing or decreasing (monotonic) in Y values. M-K Test is a non-parametric test which works for all type of distributions that means, the assumption of normality isn’t mandatory.

The assumptions under the Mann Kendall Test are:

- In absence of trend, the data observed over the period of time are identically distributed and independent which means observation are not correlated serially.
- Data Observed for the given period of time represents true conditions at the time of sampling.
- There is unbiased method of sampling, handling and measurement and representing observations of the underlying population for given period time.

Mann Kendall tests have two results, whether it rejects the null hypothesis H_0 and accepts the alternative hypothesis H_a.

Where,

H_o : No monotonic trend

H_a : Monotonic trend is present

The initial assumption is that the H_o is true and data must convince beyond a reasonable doubt before H_o is rejected and H_a is accepted.

To compute the following equation is used(Anie and Brema, 2018),

$$S = \sum_{k-1}^{n-1} \sum_{j-k+1}^{n} \operatorname{sgn}(x_j - x_k)$$

………. eq.1

If S is a positive number, observations obtained later in time trend to be larger than observation made prior.

If S is a negative number, then observations made later in time trend to be smaller than observations made prior.

To compute the variance of S,

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p-1}^{g} t_p(t_p - 1)(2t_p + 5)\right] \text{……… eq.2}$$

Where g is the number of tied groups, t_p is the number of observations in the pth group.

To compute the MK test statistic, Z_c,

$$Z_c = \frac{S-1}{\sqrt{VAR(S)}} \text{ if } S > 0 \text{………eq.3 (a)}$$

$$Z_c = 0, \text{ if } S=0 \text{………eq.3 (b)}$$

$$Z_c = \frac{S+1}{\sqrt{VAR(S)}} \text{ if } S<0 \text{………eq.3 (c)}$$

3.4. Rainwater Harvesting Potential & Design of Pilot Scale Model

Rain Water Harvesting Structures

A) Population and Study Sample

A survey through interview schedule was designed (Annexure-1) to be conducted at the household level to get their perception of the rainwater harvesting structure. Another interview schedule was to be done at public institutions, commercial buildings whether they comply with state norms and if installed, the efficiency of Rain Water Harvesting structure. The sample size of 50 was decided to conduct survey in the wards. The survey would be conducted in different wards (total 15 Wards) of Nainital town to get the perception of people from different localities.

Note: The survey has been postponed due to COVID-19 Lockdown. Hence, telephonic interview with a Hotelier has been done to design a Pilot based Project for a Hotel.

The design of RWH structure is for the rooftop of 60 m × 20 m, whereas the catchment area is 300 m^2. The rooftop is of tiles having Run-Off Coefficient Value 0.75. The rainfall intensity has been taken from IMD Nainital rainfall data of year 2009-2019. Also, the Rain Water Harvesting potential has been identified with the use of Daily Supply Log table of Naini Lake (main source) with the Harvesting Potential at different scale (% of Built Up Area, where RWH can be done).

B) Sources of Data

Primary Sources of data are:

a) Interview Schedules
b) Observation

Secondary Sources of Data are:

a) Uttarakhand State Policy,
b) Building Regulations
c) Articles
d) State Data (Log Data of lake level, supply from lake)
e) IMD Rainfall Data

Software/Tools used are:

a) Microsoft Excel

b) AutoCAD 2016

c) XLSTAT

- **Volume Estimation**

The rainfall volume storage potential has been calculated using the formula mentioned below.

$$Q = C.\ i.\ A$$

Where,

Q =Storage potential
i =Intensity of rainfall, m
C =runoff coefficient
A =Area of the catchment, m^2

The *i* "rainfall intensity" has been taken as average annual rainfall for the past 10 years (2009-2019) from IMD.

Type of Roof	*Runoff Coefficient*
Galvanized Iron Sheet	0.9
Asbestos Sheet	0.8
Tiled Roof	0.75
Concrete Roof	0.7

Fig. 3.2. Runoff Coefficient Value for different type of Roof.
Source: Manual on construction and Maintenance of Rooftop Harvesting System, UNICEF.

- **Rainwater Harvesting Potential**

The Land Use Land Cover statistics for 2020 shows that the total built-up area in Nainital is 3306600 m2. The Harvesting scale at 10%, 15%, 20%, and 25% of the built-up area forecasted the volume of rainwater can be stored by harvesting.

The value will be compared to the daily supply during the above mentioned seasons with the estimated values of harvesting volume to identify the harvesting potential. The harvesting potential should be able to decrease the stress on the lake system for the supply.

The percentage of the Shortage will be accounted for the different seasons at varying harvesting scale and it will show the percentage of the volume that has to be supplied from the lake.

4. RESULTS & DISCUSSIONS

4.1. Land Use/Land Cover Dynamics of Nainital Town using GIS techniques.

The Land Use/Land Cover classification was performed for the datasets Landsat 1-5 with resolution of 80m of 13th Dec’1980, Landsat 4-5 Level-1 with resolution of 30m of 27th Jan’2000 & Landsat 8 data with a resolution of 30m of 18th Jan’2020 using supervised classification in ERDAS IMAGINE 14 and ARCGIS software. The below are the output generated maps of Land Use/Land Cover for the year 1990, 2000, 2010, 2020.

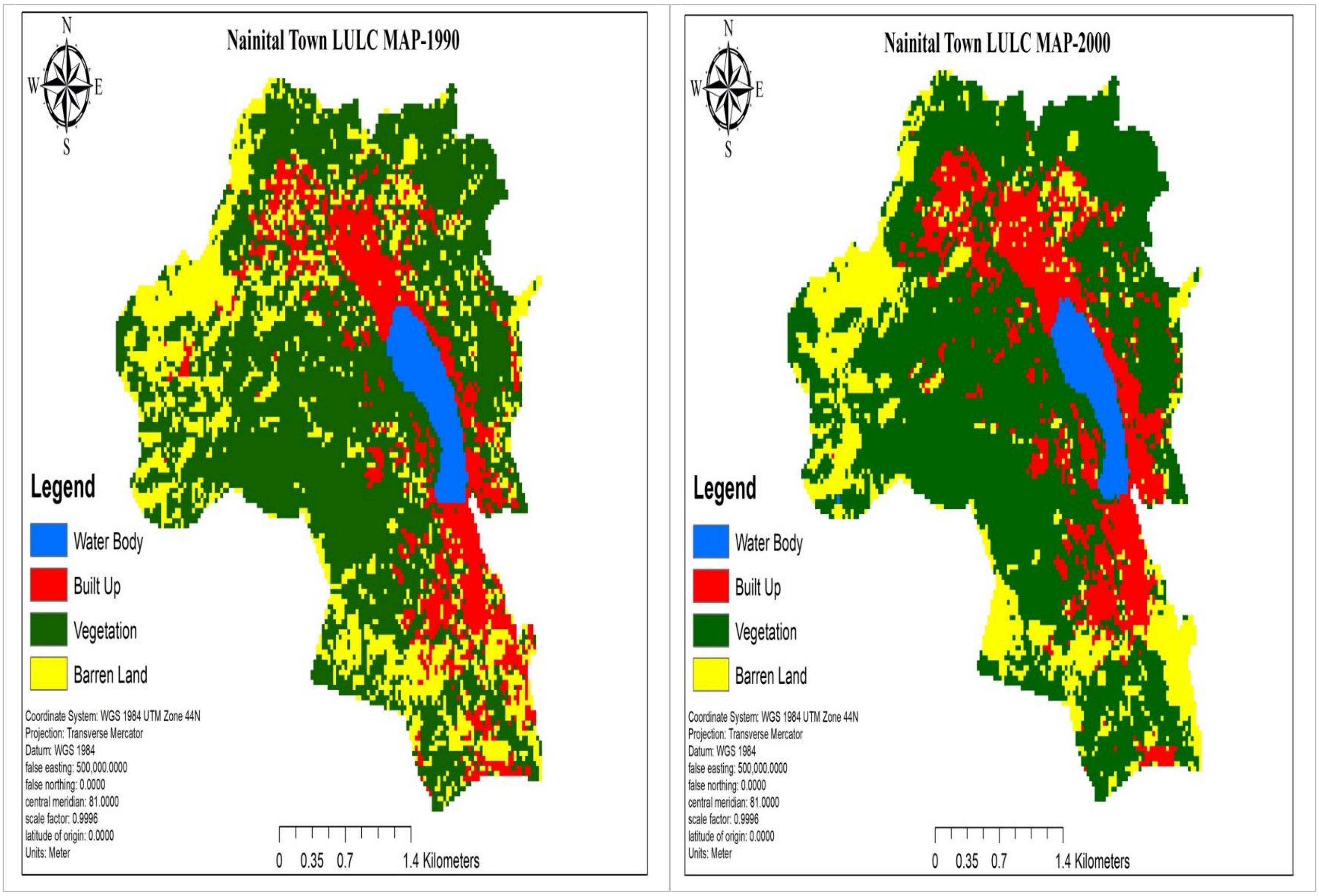

Fig.4.1. Land Use/land Cover Classification map for Year 1990 & 2000.

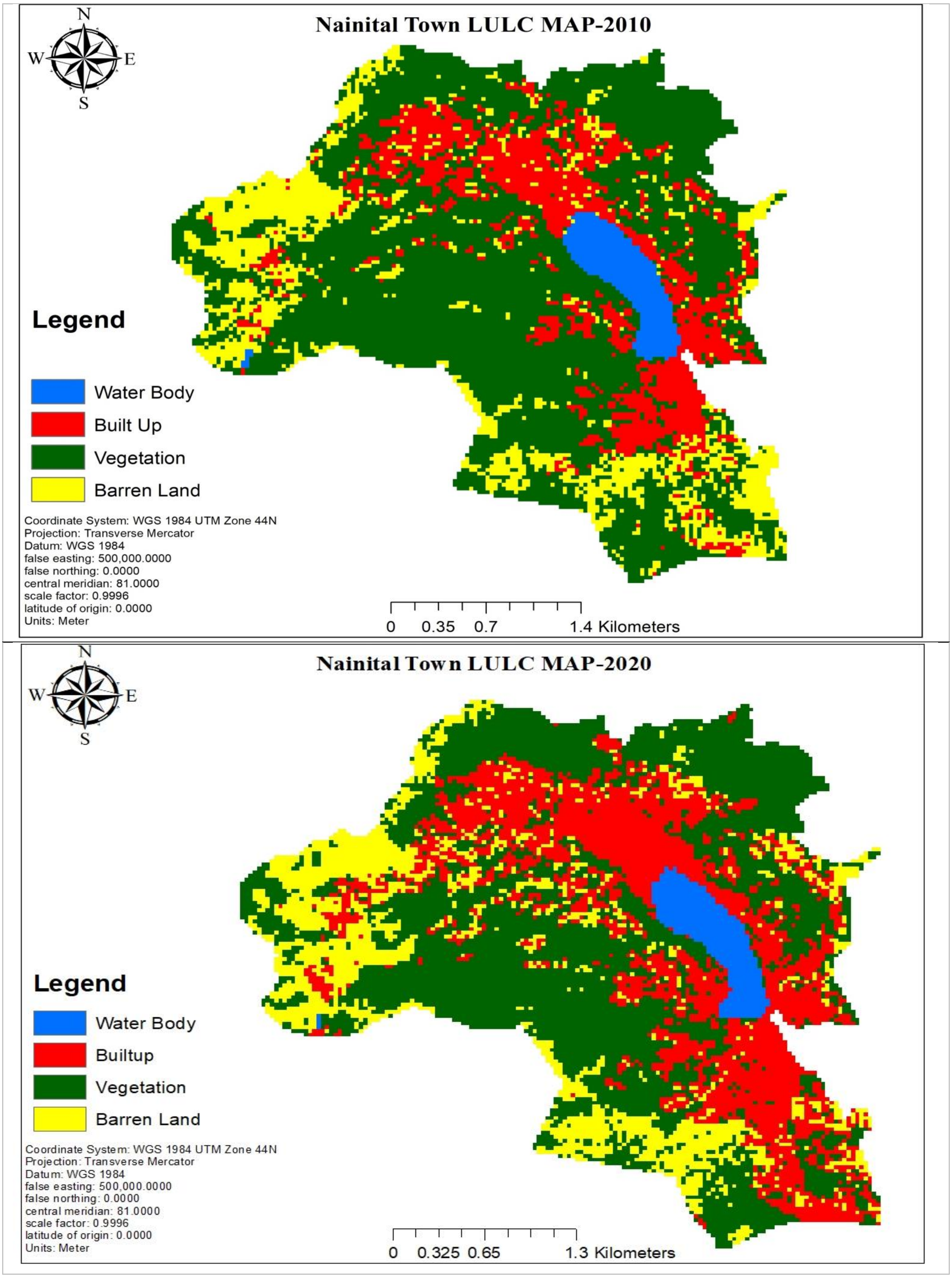

Fig.4.2 Land Use/Land Cover Classification Map for 2010,2020.

In this study, the Land Use and Land Cover were classified mainly under four classes viz. Barren Land, Water Body, Built-Up, and Vegetation. Vegetation in the study area occupies the largest share of Land Cover class (56.86, 60.75, 59.74, and 48.25 % in 1990, 2000, 2010, 2020 respectively). This implies that Vegetation has increased between 1990-2000 but between two decades 2000-2010, 2010-2020, the share percentage has declined. This is due to the expansion of urban area i.e. Built-Up and Forest fires, Landslides.

Barren Land within the study period has shown a declining trend of 24.71 % to 18.24 % from 1990-2010 but it has increased between 2010-2020 from 18.24% to 19.88 %. The declining trend in 2 decade i.e. 1990-2010 is mainly due to the few percentage of Barren Land has contributed to other classes such as Vegetation and Built-Up. It is noted that between the years 1990-2010, Vegetation has increased as well as the Built-Up area.

Water Body includes Naini Lake, Sariya Tal in the study area. The Lake covered 3.66 % of the area in 1990, whereas it declined to 3.51% in 2000. In the year 2000-2010, it increased to 3.82% & further declined in 2010-2020 to 3.55%. The increase and decrease in the area of the water body are because of the two lakes in the study area. The Naini lake has experienced encroachment, rapid urbanization such as construction at Mallital side, & on its other side i.e. Tallital in the past years has reduced the area of the lake. The Sariya tal lake is the on the west of Naini lake. This lake has been revived and developed as tourist spot around 2010, before this, it has been seen either dried up or less water in the lake due to sedimentation.

The Land Use/Land Cover classification has to be analysed using Change Detection Matrix and % Change in Area table. Change Detection has been applied for the period between 1990-2000, 2000-2010, and 2010-2020.

The Change Detection matrix between the two years shows the value of each class which has changed (whether increased or decreased) for the said period.

Table.5 (a) Change Detection Matrix for the year 1990 & 2000.

Change Detection Matrix (1990-2000)					
	Water Body	**Built Up**	**Vegetation**	**Open Space/Barren Land**	**Total 2000**
Water Body	**0.3969**	0.0045	0.0081	0	**0.4095**
Built Up	0.0135	**1.242**	0.3159	0.3618	**1.9332**
Vegetation	0.0171	0.1881	**5.9103**	0.9801	**7.0956**
Open Space/Barren Land	0	0.2898	0.4068	**1.5444**	**2.241**
Total 1990	**0.4275**	**1.7244**	**6.6411**	**2.8863**	**11.6793**

Table.5(b) Change Detection Matrix for the year 2000 & 2010.

Change Detection Matrix (2000-2010)					
	Water Body	**Built Up**	**Vegetation**	**Open Space/Barren Land**	**Total 2010**
Water Body	**0.4023**	0.0153	0.0234	0.0054	**0.4464**
Built Up	0	**1.5057**	0.3771	0.243	**2.1258**
Vegetation	0.0072	0.2439	**6.1758**	0.5499	**6.9768**
Open Space/Barren Land	0	0.1683	0.5193	**1.4427**	**2.1303**
Total 2000	**0.4095**	**1.9332**	**7.0956**	**2.241**	**11.6793**

Table.5 (c) Change Detection Matrix for the year 2010 &2020.

Change Detection Matrix (2010-2020)					
	Lake	**Built Up**	**Vegetation**	**Open Space/Barren**	**Total 2020**
Water Body	**0.4104**	0.0027	0.0018	0	**0.4149**
Built Up	0.0234	**1.7865**	0.9522	0.5445	**3.3066**
Vegetation	0.009	0.09	**5.2758**	0.261	**5.6358**
Open Space/Barren	0.0036	0.2466	0.747	**1.3248**	**2.322**
Total 2010	**0.4464**	**2.1258**	**6.9768**	**2.1303**	**11.6793**

*Values are in Area. Unit= Km^2

Table.6 Land use land and cover change of Nainital Town 1990–2020

Land Use Class	**Land use land cover area (Km^2) and % share**							
	Area (Km^2) 1990	**% of Share**	**(Area Km^2) 2000**	**% Share**	**Area (Km^2) 2010**	**% Share**	**(Area Km^2) 2020**	**% Share**
Lake	0.4275	3.66	0.4095	3.51	0.4464	3.82	0.4149	3.55
Built Up	1.7244	**14.76**	1.9332	**16.55**	2.1258	**18.20**	3.3066	**28.31**
Vegetation	6.6411	56.86	7.0956	60.75	6.9768	59.74	5.6358	48.25
Barren Land	2.8863	24.71	2.241	19.19	2.1303	18.24	2.322	19.88

Rate of Land Use and Land Cover Dynamics in the Study Area

Table.7 (a) Change in Land Use Land Cover Area in (%) between 1990-2000

Class	Area 1990	Area 2000	% Change
Water Body	0.4275	0.4095	**-4.210526316**
Built Up	1.7244	1.9332	**12.1085595**
Vegetation	6.6411	7.0956	**6.843745765**
Open Space/Barren Land	2.8863	2.241	**-22.35734331**

Table.7 (b) Change in Land Use Land Cover Area in (%) between 2000-2010

Class	Area 2000	Area 2010	% Change
Water Body	0.4095	0.4464	**9.010989**
Built Up	1.9332	2.1258	**9.962756**
Vegetation	7.0956	6.9768	**-1.67428**
Open Space/Barren Land	2.241	2.1303	**-4.93976**

Table.7 (c) Change in Land Use Land Cover Area in (%) between 2010-2020

Class	Area 2010	Area 2020	% Change
Water Body	0.4464	0.4149	**-7.056451613**
Built Up	2.1258	3.3066	**55.54614733**
Vegetation	6.9768	5.6358	**-19.22084623**
Open Space/Barren Land	2.1303	2.322	**8.998732573**

The rate of change of Vegetation, Built-Up, Water Body, and Barren Land has been presented in Table 7 (a), (b), (c). The result shows that the Land Cover is fixed though the area has changed with time.

The analysis indicates that between 1990-2000, a declining trend has been noticed in the Water Body area by 4.21%. but it increased between 2000-2010 by 9.01 % due to the Sariya Tal lake area added in the total area of Water Body. In 1990, the Sariya Tal lake was dried up and the remote sensing technique counted in the barren land. Though a 7.05 % decline has been noticed in the water body area between the years 2010-2020 due to rapid growth in population, tourism inflow leads to an increase in the built-up area of the town. The lake is congested from its two ends with markets, two to five-storied houses. The surrounding of Lake consists of residential areas and housing units are located near the Mall Road that is parallel to the lake, as per the report Urban Development in the Lake region (Shodhganga Report). The Built-Up area 12.1% to 55.5% in 3 decades. The rapid growth of population, tourism influx, and the development of the town as Tourist Hill Town has increased the Built-Up area. In this period, rapid urbanization, as well as anthropogenic activities such as the construction of roads, parking areas, hotels, schools, and recreational sites, has contributed to an increment of the Built-Up area and making the town susceptible to landslides (Tiwari & Joshi, 2016). The same above reason goes for the decline in the Vegetation area between 2000-2020 by 19.2%. The encroachment on the slopes of the Nainital has made a fall in the Vegetation area. The decline in Vegetation has also resulted due to Forest Fires in the state of Uttarakhand in 2016. The Forest in 9 districts of Uttarakhand converted Vegetation Land into Barren land, a sudden decline in the Vegetation area.

4.2. Surface Runoff according to Land Use and rainfall analysis from 1990-2019.

4.2.1. Surface Runoff Using SCS-CN method

The **Surface Run-off** has been generated using the SCS-CN method computing different values of the Built-Up area. The Built-Up area and other classes statistics have been taken from Land Use/Land Cover Classification for the years 1990,2000,2010. In Table.9 below, the % Run-off is the Volume of Rainfall that has been converted into Surface Runoff (Q m3) in the season of Monsoon. As the value of the Built-Up area increases, the Runoff volume also increases which indicates that the impermeable layer plays an important role in generating Surface Runoff.

Also, the Runoff is only generated for the values of precipitation more than 0.1 S i.e. P > 0.1S.

Table.8 Statistics showing different Surface Runoff generated by SCS - CN method.

Year	Built Up (%)	Rainfall (Monsoon) mm	Rainfall (Volume) (m^3)	Q (m^3)	% Run Off
1990	**14.76**	852.73	9959289.489	978161.823	**9.82**
2000	**16.55**	778.26	9089532.018	1142142.694	**12.57**
2010	**18.2**	1429.2	16692055.56	3545047.27	**21.24**

4.2.2. Rationale method

Table.9 Statistics showing different Surface Runoff generated byRationale formula.

Year	Built Up (%)	Rainfall (Monsoon) mm	Rainfall (Volume) (m^3)	Q (m^3)	Run off %
1990	**14.76**	852.73	9959289.489	3366450.13	**33.8**
2000	**16.55**	778.26	9089532.018	3271447.04	**35.9**
2010	**18.2**	1429.2	16692055.56	6196268.02	**37.1**

The rationale formula used here calculates the Surface Runoff (cumec) for different classes individually as C values and Area varies for different type of surfaces. The Surface Runoff generated here with Rationale method shows the increased value than SCS-CN method. The Rainfall intensity here accounted is constant for the year, i.e. it generates the Surface Run-off for each precipitation in the particular year. In the year 2010, 1429.2 mm of rainfall has been accounted as "i" in the rationale formula and this is the major reason of getting increased runoff (%) than other method.

4.2.3. Man Kendall Rainfall Trend Analysis Test.

Seasonal Wise

Table. 10 Estimated Sen's Slope and Kendall's test statistics (Z_c) values from 1990 to 2019.

Variable	Mean	Std. deviation	p-value (Two-tailed)	Significance Level (alpha)	Z Statistics	Sen's Slope
Pre Monsoon	236.71	212.774	0.002	<0.05	3.07	386.901
Monsoon	1856.35	1112.396	0	<0.05	3.68	41.51
Post Monsoon	48.763	77.623	0.712	>0.05	0.37	0.112
Winter	134.798	124.024	0.842	>0.05	-3.66	-4.759

The statistics from the Mann-Kendall Test indicates that Post Monsoon months (October, November) and Winter months (January-February), null hypothesis (H0) can't be rejected which means these months doesn't show any trends as p-value is more than Significance level (α) 0.05 and one cannot reject the null hypothesis H0.

The Mann -Kendall Test indicates Monsoon months (June-September) and Pre-monsoon months (March-May), one should reject the null hypothesis as value p-value is less than Significance level (α) 0.05 and accept alternate hypothesis Ha.

The average rainfall for the study period of 29 year is 2250.754 mm. The month of July has been observed as maximum average rainfall of 630.3055 mm and second highest month is August with the average rainfall of

534.709 mm for the study period of 29 years. The lowest average rainfall has been observed in the month of November having 10.564 mm of rainfall whereas second lowest average rainfall of 12.591 mm in the month of December has been observed for the study period of 29 years from 1990-2019.

In the non-parametric Mann-Kendall test, trend of rainfall for 29 years from January to December has been calculated for each season individually together with the Sen’s magnitude slope by the use of XLSTAT 2020 software.

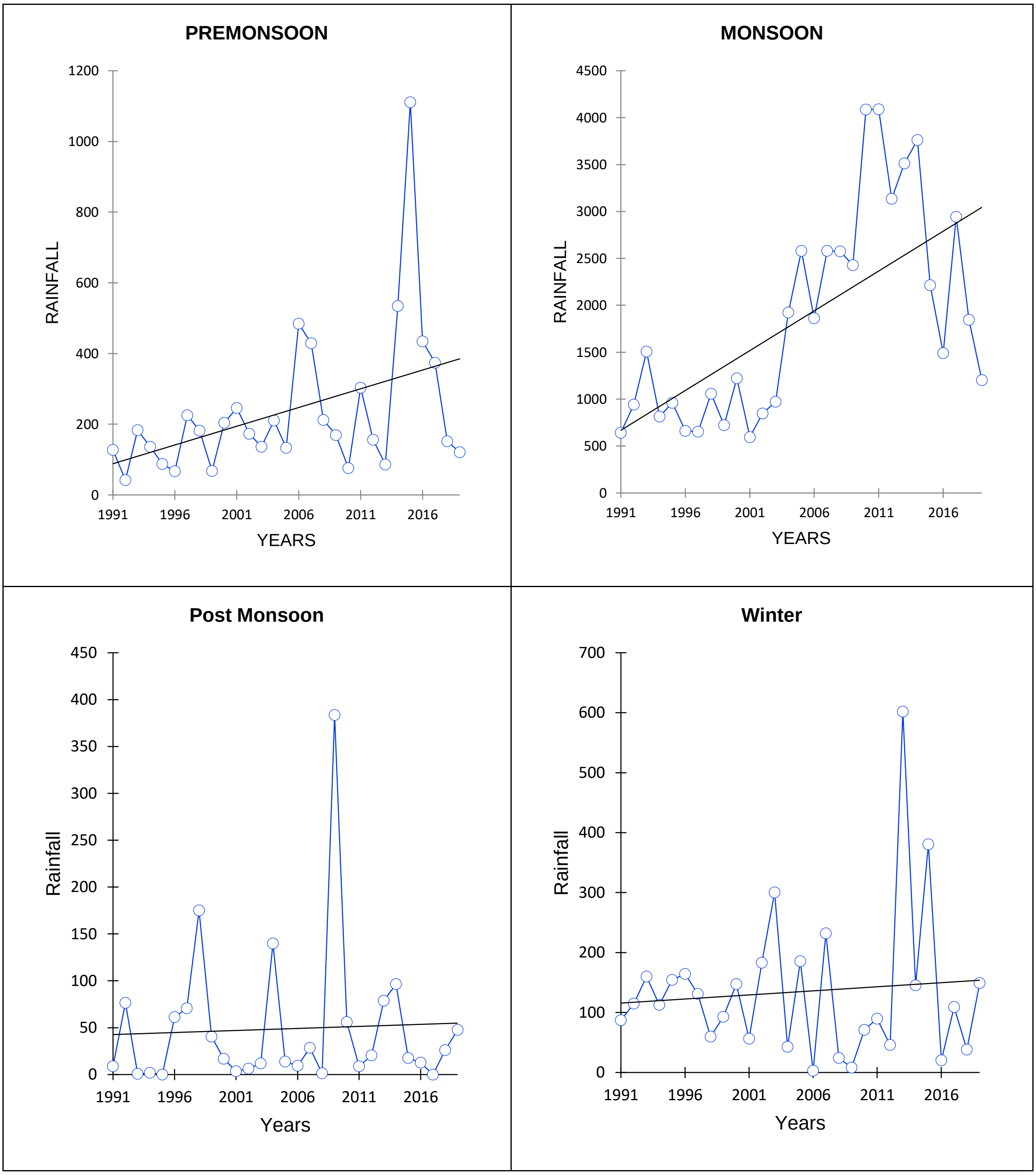

Fig.4.3. Mann-Kendall Test for Seasonal Rainfall Variation(mm).

Fig.4.4. Shows Annual Total Rainfall variation, providing the information that maximum rainfall of 4538.31mm in the year 2014 and minimum rainfall intensity of 865.01 mm occurred in the year 1991 in the period of 29 years i.e. from 1990-2019. The 'wet year' is 2014 where as 1991 'dry year' among the study period.

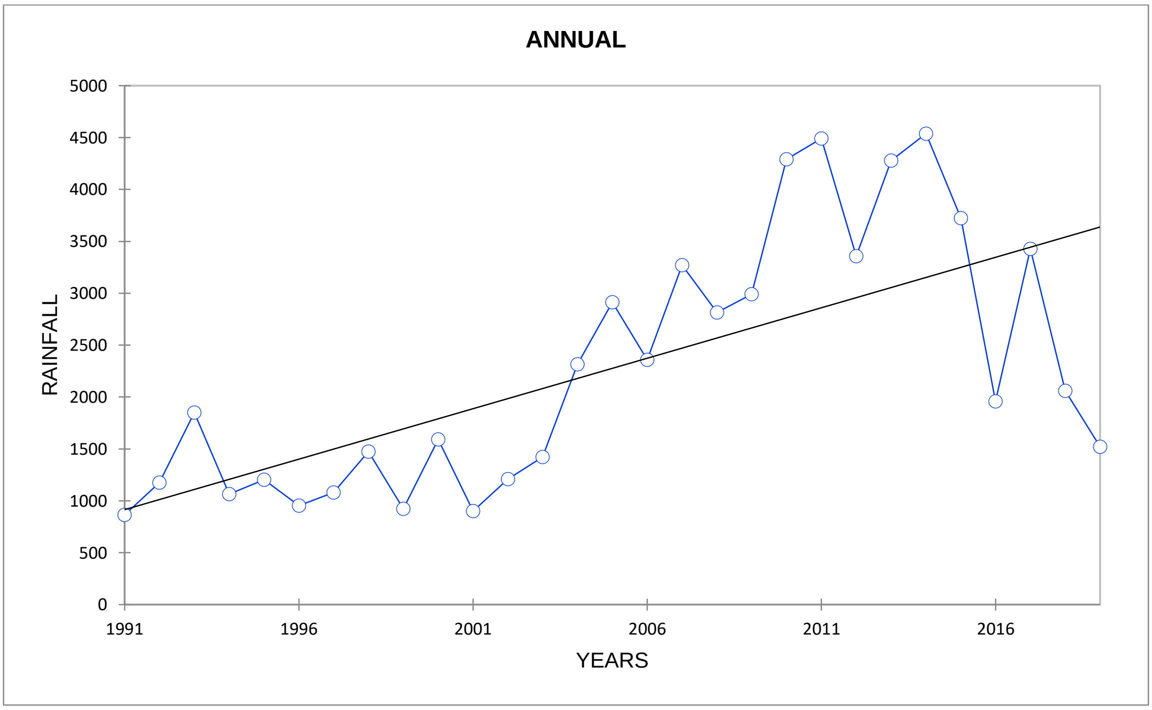

Figure.4.4. Annual Rainfall variation of 29 years of each year (1990-2019).

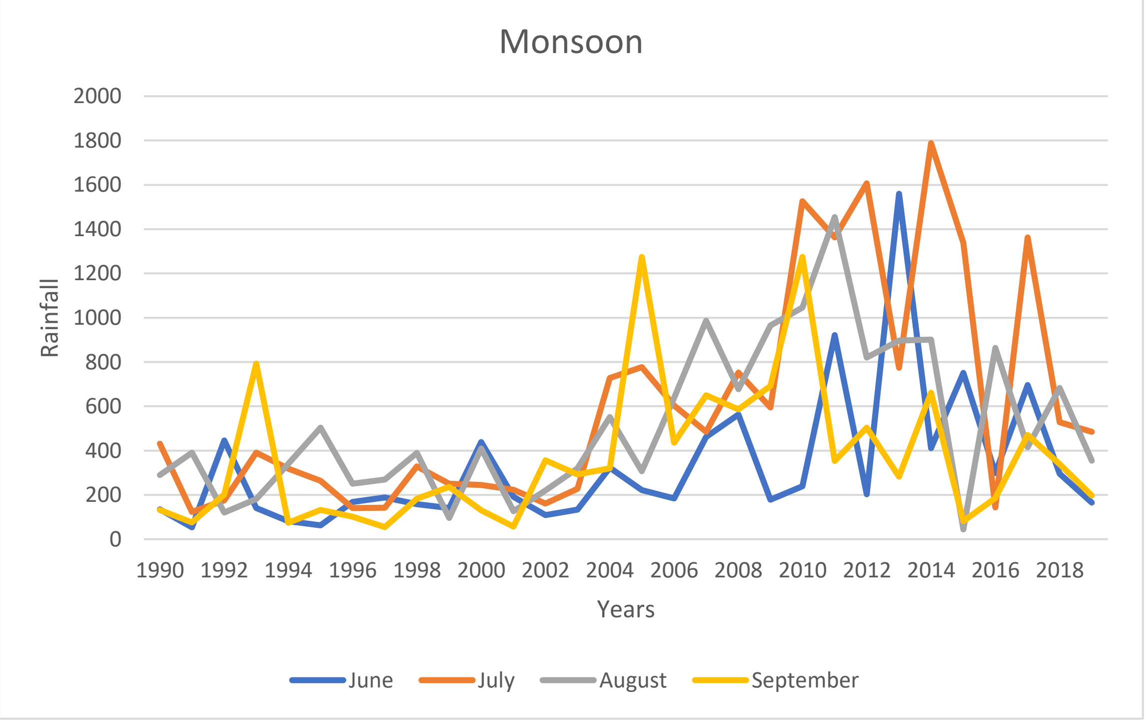

Fig.4.5. Seasonal Rainfall Variation (Month Wise)-Monsoon.

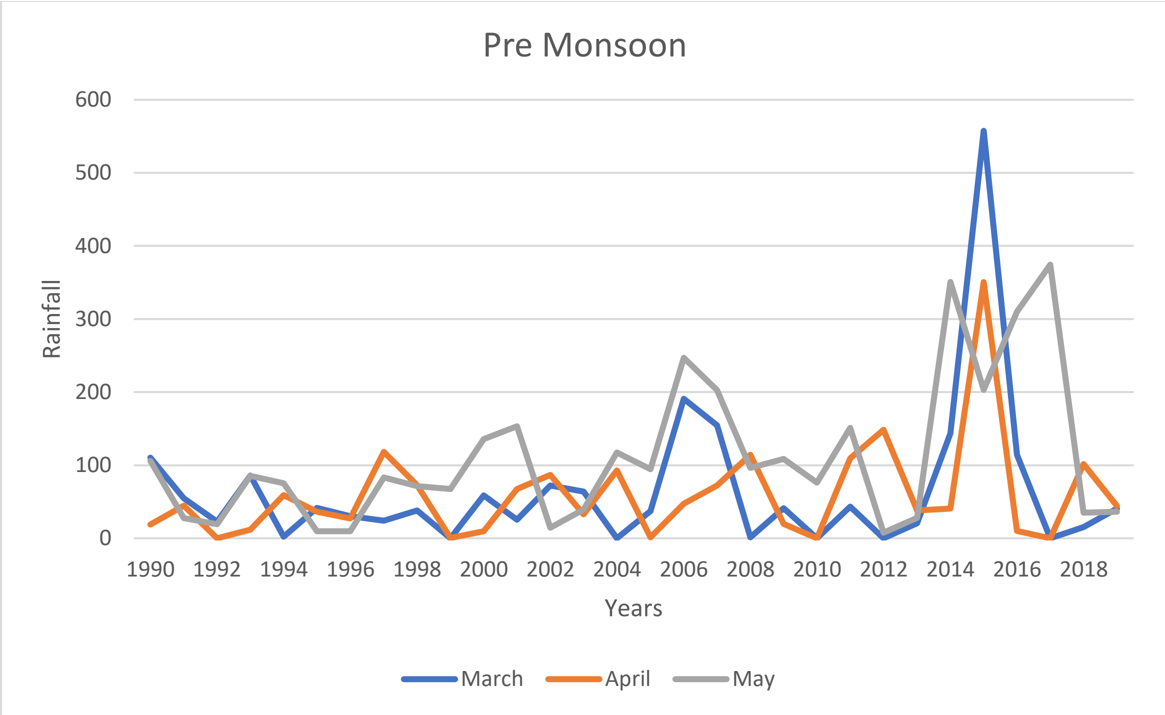

Fig.4.6. Seasonal Rainfall Variation (Month Wise)- Pre-Monsoon.

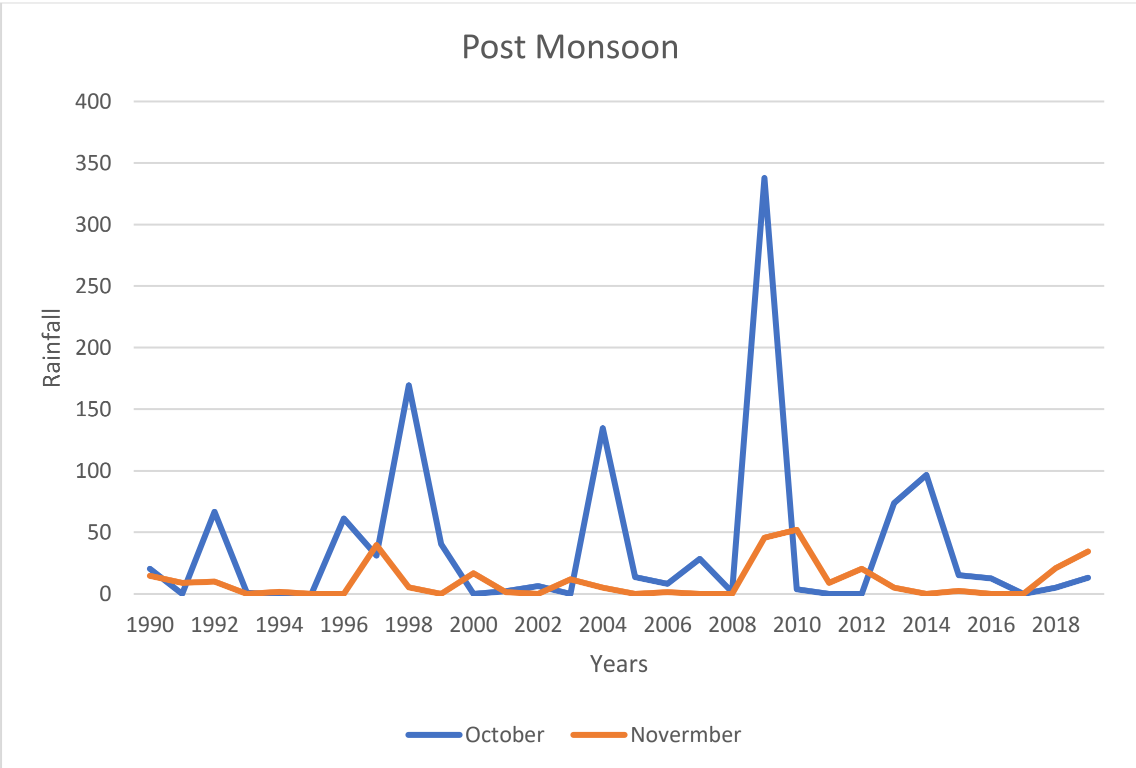

Fig.4.7. Seasonal Rainfall Variation (Month Wise)- Post-Monsoon.

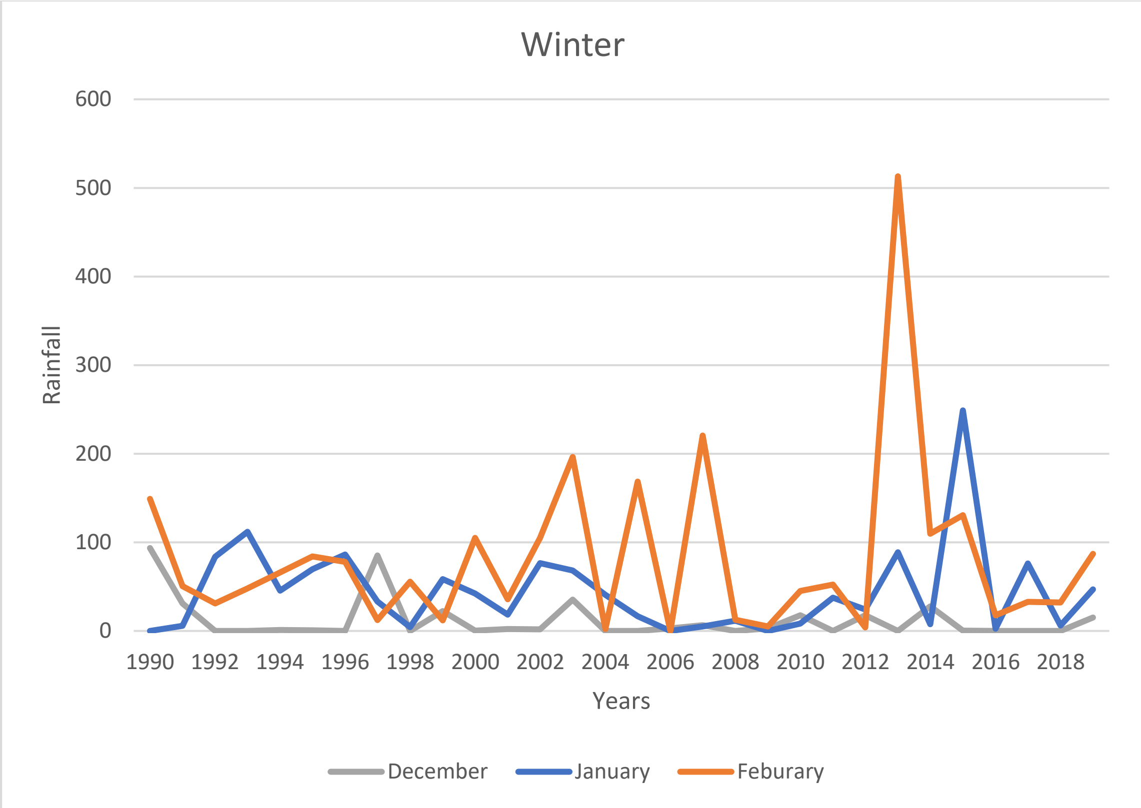

Fig.4.8. Seasonal Rainfall Variation (Month Wise)-Monsoon.

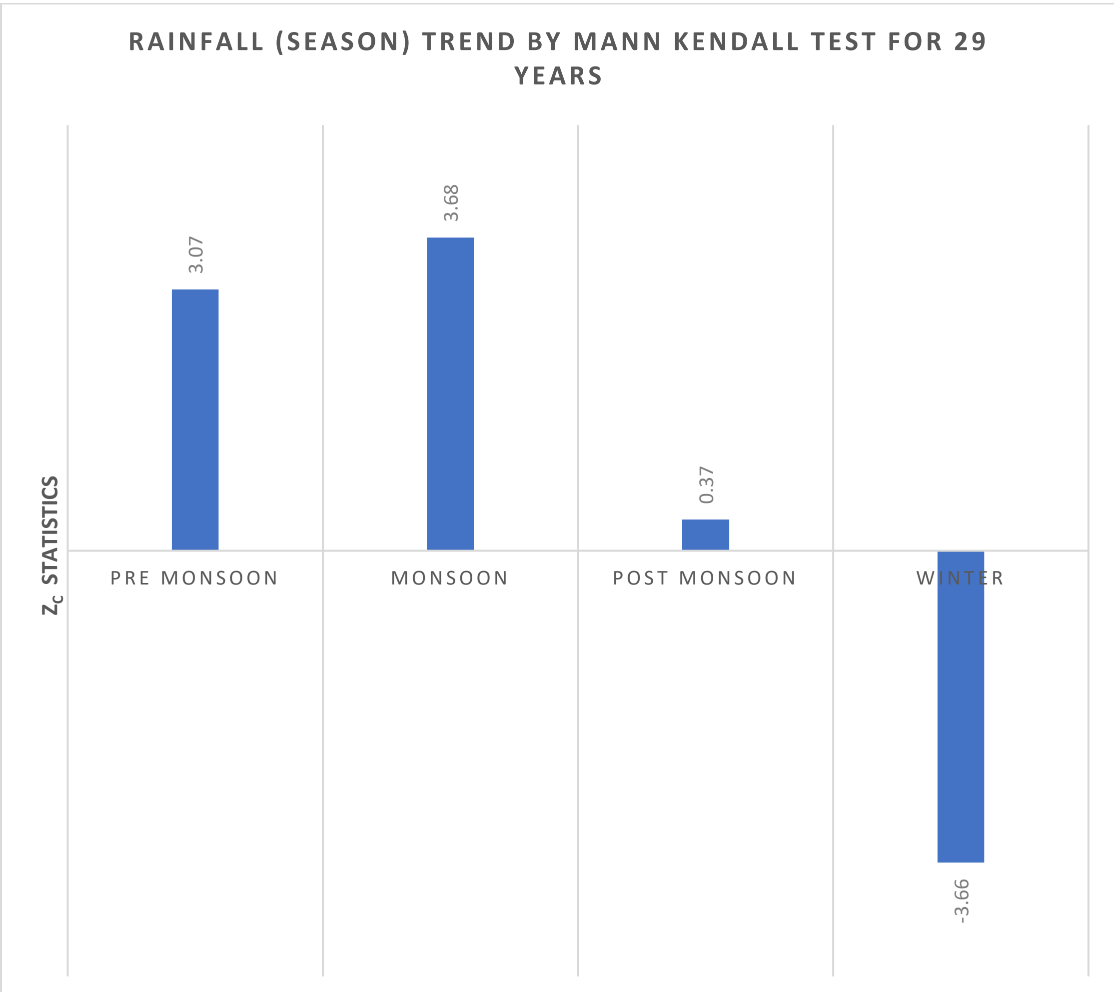

Fig.4.9. Trend of Z_c for different Seasons for 30 Years.

The months of June, July, August, September shows the highest positive trend observed as 3.68 that is, mainly due to Monsoon season. The highest negative trend of -3.66 is shown during the months of December, January, February. The individual month study will show the exact month having highest positive trend and highest negative trend.

4.3. Rainwater harvesting potential estimation and design of Rain Water Harvesting structure for a commercial building.

The Rainwater Harvesting potential identified for different scale of Built-Up area using statistics of 2020 Land Use Land Cover. The supply from the Lake has been compared with Rain Water Storage Potential for different seasons.

Summer Season

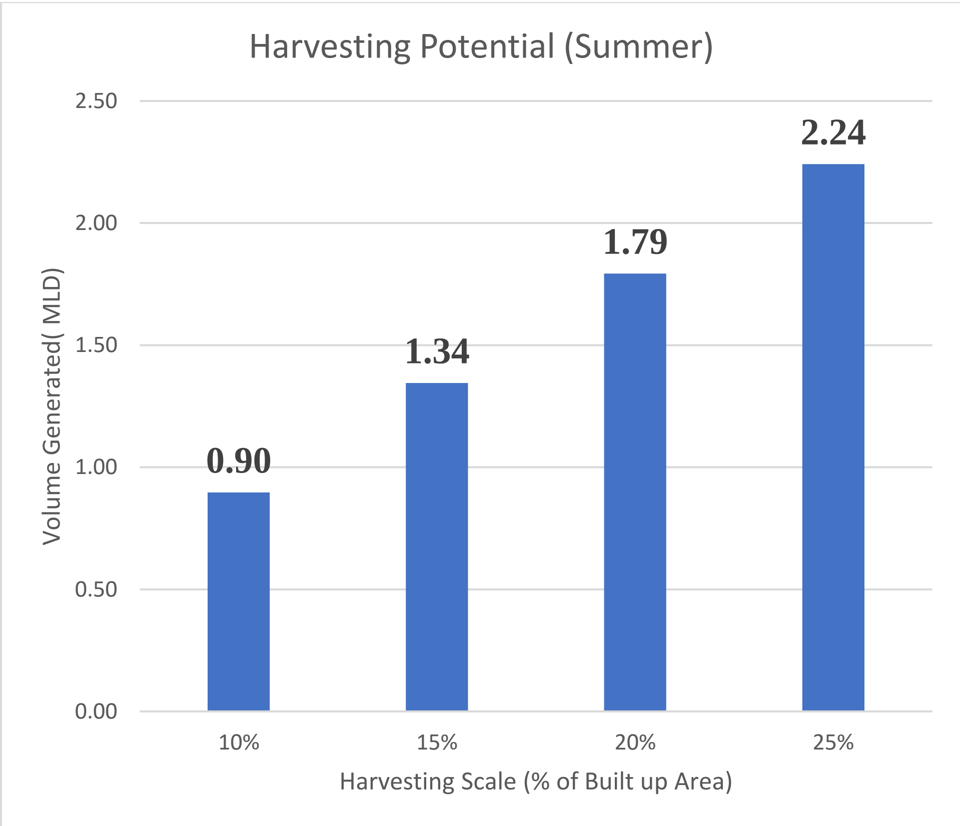

Fig.4.10. Harvesting Potential identified in MLD at different scale for Summer.

Table.11 Calculation for volume of Storage during Summer Season.

Summers (Harvesting Potential) (Mar-May)							
Harvesting Scale	C	Intensity (m/day)	Potential Area (sq. meter)	Q (MLD) Generated	Q (MLD) Supplied	Difference	Shortage (%)
10%	0.8	0.1039	330660	0.90	13.05	-12.15	-93.13
15%	0.8	0.1039	495990	1.34	13.05	-11.71	-89.70
20%	0.8	0.1039	661320	1.79	13.05	-11.26	-86.26
25%	0.8	0.1039	826650	2.24	13.05	-10.81	-82.83

Harvesting scale is the that percentage of total built up area. The average rainfall intensity for the summer season is 103.9 mm. The average water supplied from the lake is 13.05 (MLD) in the Nainital town. At different Harvesting Scale, the storage can be generated is 0.90 MLD at 10%, which means at this scale 93.13 % volume water has to be supplied from the Lake. Similarly, 1.34 MLD can be generated at 20 % scale of Harvesting creating shortage of 89.9%, that has to be catered from Lake. 1.79 and 2.24 MLD at 20 % and 25% of Harvesting scale respectively could be storage volume, further reducing the stress on Lake to supply water. During summer season as per the Lake supply log table for the year 2019, if Rain Water Harvesting structure is installed at different scale varying from 10% to 25% of the total built up area, the volume of storage generated can reduce the demand to be supplied from the Lake.

Monsoon Season

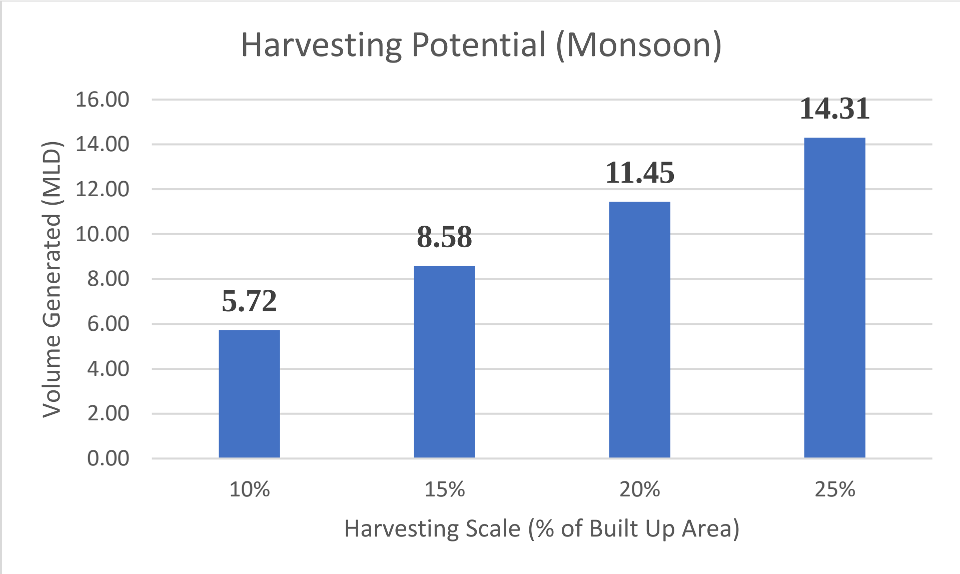

Fig.4.11. Harvesting Potential identified in MLD at different scale for Monsoon.

Table.12 Calculation for volume of Storage during Monsoon Season.

Monsoon (Harvesting Potential) (June-Sept)							
Harvesting Scale	C	Intensity (m/day)	Potential Area (sq. meter)	Q (MLD) Generated	Q (MLD) Supplied	Difference	Shortage (%)
10%	0.8	0.6599	330660	5.72	14.25	-8.53	-60%
15%	0.8	0.6599	495990	8.58	14.25	-5.67	-40%
20%	0.8	0.6599	661320	11.45	14.25	-2.80	-20%
25%	0.8	0.6599	826650	14.31	14.25	0.06	0.41%

Harvesting potential calculated for the Monsoon season where the Intensity of rainfall is 659.9 mm during the rainy season (average) between June-September. At the different scale (Table.12) of Harvesting , i.e. at 10%, 15%, 20%, 25% the volume of storage generated are 5.72 MLD, 8.58 MLD, 11.45 MLD and 14.31 MLD respectively. The volume of storage generated at 25% of the Built-Up area is 14.31 MLD which is about 0.006MLD more than the supplied by the Lake, making 0.41% additional. The monsoon month can make the town self-reliant in terms of water supply where the town can meet its demand by harvesting the rainwater which currently is converted into surface runoff from the built-up area.

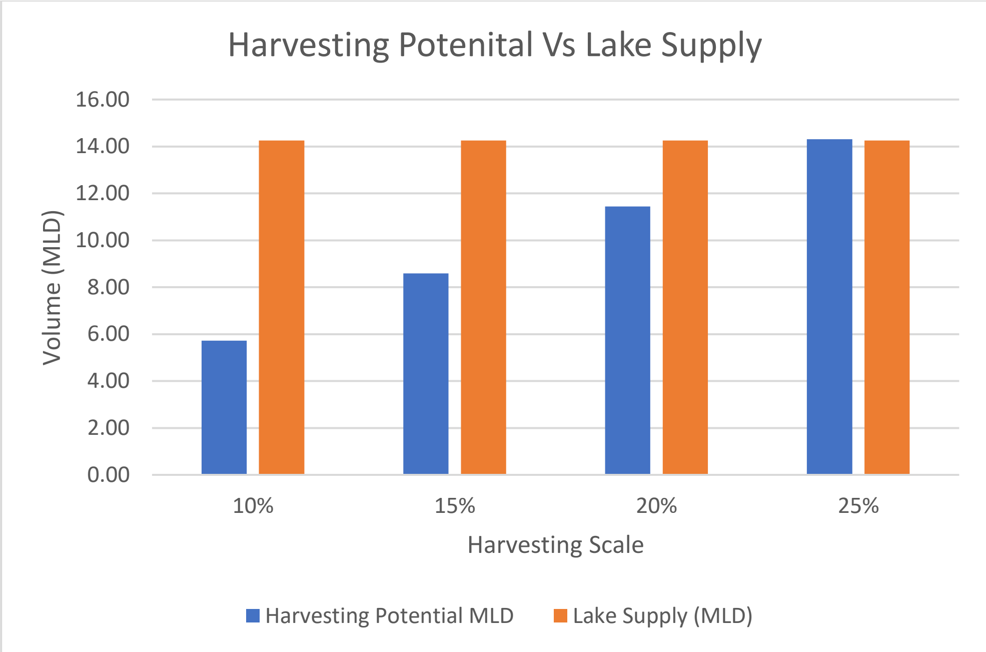

Fig.4.12. Harvesting Potential Vs Lake Supply during Monsoon.

Winter Season

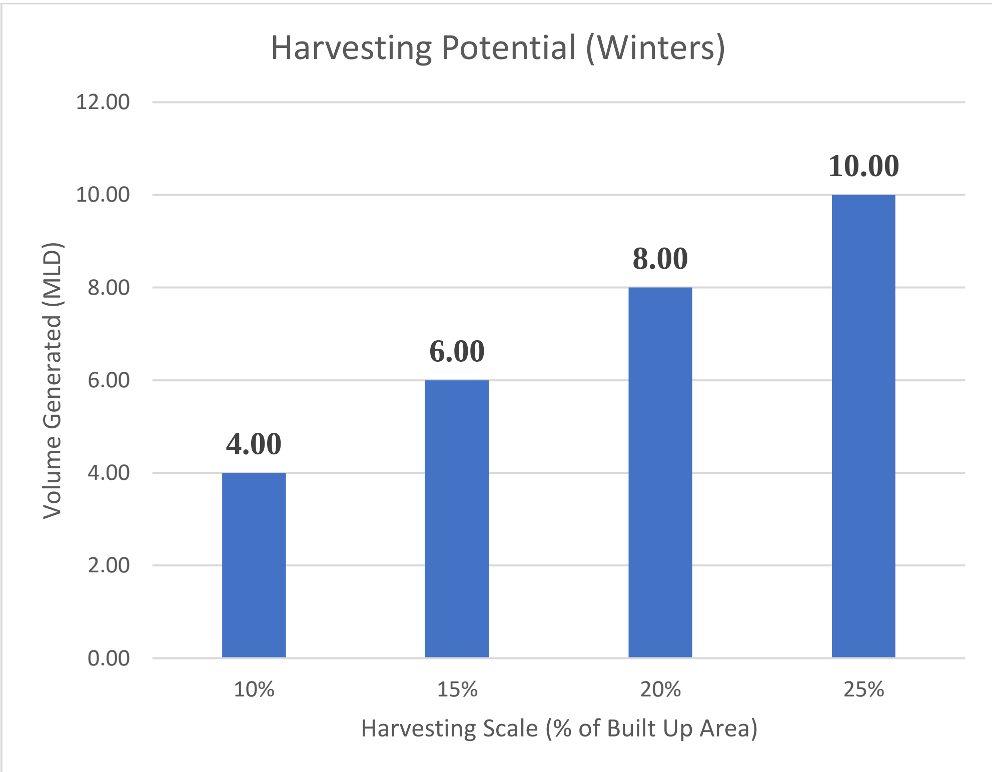

Fig.4.13. Harvesting Potential identified in MLD at different scale for Winters.

Table.13 Calculation for volume of Storage during Winter Season.

Winters (Harvesting Potential) (Oct-Feb)							
Harvesting Scale	**C**	**Intensity (mm/day)**	**Potential Area**	**Q (MLD) Generated**	**Q (MLD) Supplied**	**Difference**	**Shortage (%)**
10%	0.8	0.4566	330660	4.00	12.51	-8.51	-68.03
15%	0.8	0.4566	495990	6.00	12.51	-6.51	-52.04
20%	0.8	0.4566	661320	8.00	12.51	-4.51	-36.06
25%	0.8	0.4566	826650	10.00	12.51	-2.51	-20.07

Harvesting Potential for winter season identified at a different scale of 10%, 15%, 20%, 25%, and the volume of storage calculated as 4 MLD, 6MLD, 8MLD, 10MLD respectively. The average daily supply during Winter is 12.51 MLD and at 25% Harvesting Scale volume of storage potential as 12.51 MLD which caters around 80% of the volume of water supplied in Nainital Town from the Lake. There is a chance to increase more volume of storage as harvesting potential with an increase in harvesting scale, leading to reduce the pressure on the lake for supply and maintaining its lake.

Rainwater Harvesting Design

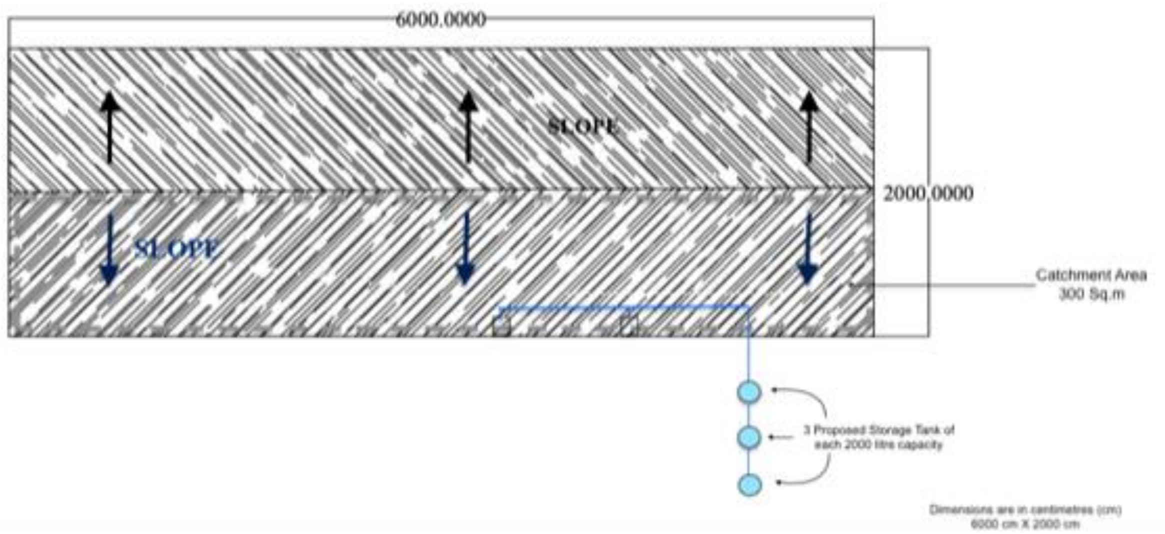

Fig.4.14. Proposed Pilot

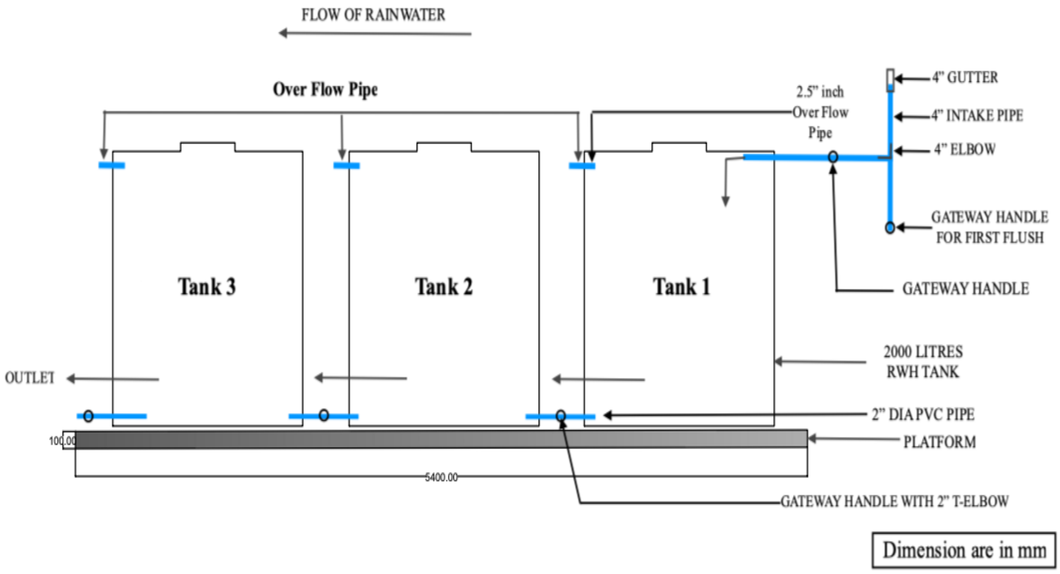

Fig.4.15. Detail Schematic of RWH System

Table.14 Calculation for RWH potential storage

Area (m^2)	C	I (mm)	Efficiency	Potential Storage (L)
300	0.75	305	80%	**54900**

Here, I= Mean Rainfall for Nainital in ten years (2009-2019).

C= Tile Roof Run off coefficient.

The RWH structure can capture the volume of 54900L of rain water from rooftop catchment area of 300 m^2. In this calculation, the efficiency as 80% to calculate more realistic figure.

The 3 conventional 2000Litre capacity tanks will be installed to store the rainwater from the roof having catchment area of 300m^2. The cost calculation for the installation of RWH structure has been given in Annexure.

CONCLUSION

The Land Use/ Land Cover map and statistics through change detection matrix as well as a percentage in areas for each class with year will reflect the increase in built-up area as well as a decrease in vegetation due to forests have been cut down for building or incidents of forest fires have been reported in the year 2016 in the town as well as in-state. The estimation of runoff using the SCS-CN method will give the volume of runoff generated in the year during the rainy season by a different type of Land Use/Land Cover as the urbanization increases the value of runoff whereas, vegetation and forest covers reduce it because of infiltration and storage capacity of the soil increases.

The Surface Runoff generated using SCS-CN method, gives the runoff depth for the precipitation greater than 0.1S whereas rationale formula uses the rainfall intensity for the season. This results in high runoff generation by rationale formula is higher than SCS-CN method, but SCS-CN method gives more realistic as it depends on Soil group, Land use type and AMC conditions. There is a gap in rationale method for generating runoff for different land cover type and it accounts uniform rainfall intensity. Also, the observed data of surface runoff generated for Nainital town is not published and laboratory tests on Rainfall Simulator to get the surface runoff according the Land Use type couldn't be performed due to current situation. Hence, the data validation for this objective is not done yet.

In the current scenario, a rainwater harvesting structure is necessary to meet up the water shortages in hilly regions. The water insecurity in the Himalayan regions has made the introduction of RWH structures prominent in the Himalayan states. RWH structures can be installed at hotels, commercial buildings making them self-reliant in the hill town of Nainital, it will help in maintaining the lake level as stored water can be used for general purposes. The RWH potential estimated for different scale predicts the surface runoff can be captured and stored for the future use. The calculation shows that, if RWH structures are installed in 25% of built-up areas, during the monsoon the supply from Lake can be catered by storing the rain water. Rainwater Harvesting Structure can store the rain water which can be used for household and other purposes. Also, hoteliers should install rainwater harvesting structure to store the rainwater to reuse it in toilets, washing and gardening purposes which can further lessen down the stress on lake for supply during the peak season. The Rainwater Harvesting Structures can make the hill town sustainable in terms of water conservation and can help the authorities to maintain the lake level throughout the year.

References

Anie John, S. and Brema, J. (2018) ‘Rainfall trend analysis by Mann-Kendall test for Vamanapuram river basin, Kerala’, *International Journal of Civil Engineering and Technology,* 9(13), pp. 1549–1556.

Bhagat, N. K. (2016) ‘ESTIMATION OF SCS-CN FOR LOWER MAHI BASIN , The Soil Conservation Service Curve Number (SCS-’, 4(4), pp. 61–63.

Chakravarti, A. and Jain, M. K. (2014) ‘Experimental invesitigation and modeling of rainfall runoff process’, *Indian Journal of Science and Technology,* 7(12), pp. 2096–2106.

kumar, A. and Pushplata (2015) ‘Building regulations for hill towns of India’, *HBRC Journal*. Housing and Building National Research Center, 11(2), pp. 275–284. doi: 10.1016/j.hbrcj.2014.06.006.

Mishra, A. *et al.* (2013) ‘Rainwater Harvesting : An Effective Tool for Water Crises & its Management in India Scenario’, *International Journal of Advanced Research and Technology,* 1(1), pp. 10–13.

Rawat, J., Biswas, V. and Kumar, M. (2004) ‘Quantifying Land Use / Cover Dynamics of Nainital Town (India) Using Remote Sensing and GIS Techniques’, *Asian Journal of Geoinformatics,* 13(2), pp. 7–12.

Shuster, W. D., Pappas, E. and Zhang, Y. (2008) ‘Laboratory-scale simulation of runoff response from pervious-impervious systems’, *Journal of Hydrologic Engineering,* 13(9), pp. 886–893. doi: 10.1061/(ASCE)1084-0699(2008)13:9(886).

Singh, H. P. *et al.* (2011) ‘Narrowing the Demand and Supply Gap Through Rooftop Water Harvesting - a Case Study of Kutlehar Area in Shiwalik Hills of Lower Himalayas’, 2(1), pp. 103–108.

Singh, S. *et al.* (2020) ‘Urbanisation and water insecurity in the Hindu Kush Himalaya: Insights from Bangladesh, India, Nepal and Pakistan’, *Water Policy,* 22(March), pp. 9–32. doi: 10.2166/wp.2019.215.

Tiwari, P. ., Joshi, A. and Joshi, B. (2018) ‘Urban Growth in the Himalayas: Understanding the Process and Options for Sustainable Development’, *Journal of Urban and Regional Studies on Contemporary India*, 4(2), pp. 15–27.

Tiwari, P. C. and Joshi, B. (2016) ‘Rapid urban growth in mountainous regions: The case of Nainital, India – UGEC Viewpoints’, *Ugec Viewpoints,* (Figure 1), p. 1. Available at: https://ugecviewpoints.wordpress.com/2016/03/29/rapid-urban-growth-in-mountainous-regions-the-case-of-nainital-india/.

Anie John, S. and Brema, J. (2018) 'Rainfall trend analysis by Mann-Kendall test for Vamanapuram river basin, Kerala', *International Journal of Civil Engineering and Technology*, 9(13), pp. 1549–1556.
Bhagat, N. K. (2016) 'ESTIMATION OF SCS-CN FOR LOWER MAHI BASIN , The Soil Conservation Service Curve Number (SCS-', 4(4), pp. 61–63.
Chakravarti, A. and Jain, M. K. (2014) 'Experimental invesitigation and modeling of rainfall runoff process', *Indian Journal of Science and Technology*, 7(12), pp. 2096–2106.
kumar, A. and Pushplata (2015) 'Building regulations for hill towns of India', *HBRC Journal*. Housing and Building National Research Center, 11(2), pp. 275–284. doi: 10.1016/j.hbrcj.2014.06.006.
Mishra, A. *et al.* (2013) 'Rainwater Harvesting : An Effective Tool for Water Crises & its Management in India Scenario', *International Journal of Advanced Research and Technology*, 1(1), pp. 10–13.
Rawat, J., Biswas, V. and Kumar, M. (2004) 'Quantifying Land Use / Cover Dynamics of Nainital Town (India) Using Remote Sensing and GIS Techniques', *Asian Journal of Geoinformatics*, 13(2), pp. 7–12.
Shuster, W. D., Pappas, E. and Zhang, Y. (2008) 'Laboratory-scale simulation of runoff response from pervious-impervious systems', *Journal of Hydrologic Engineering*, 13(9), pp. 886–893. doi: 10.1061/(ASCE)1084-0699(2008)13:9(886).
Singh, H. P. *et al.* (2011) 'Narrowing the Demand and Supply Gap Through Rooftop Water Harvesting - a Case Study of Kutlehar Area in Shiwalik Hills of Lower Himalayas', 2(1), pp. 103–108.
Singh, S. *et al.* (2020) 'Urbanisation and water insecurity in the Hindu Kush Himalaya: Insights from Bangladesh, India, Nepal and Pakistan', *Water Policy*, 22(March), pp. 9–32. doi: 10.2166/wp.2019.215.
Tiwari, P. ., Joshi, A. and Joshi, B. (2018) 'Urban Growth in the Himalayas: Understanding the Process and Options for Sustainable Development', *Journal of Urban and Regional Studies on Contemporary India*, 4(2), pp. 15–27.
Tiwari, P. C. and Joshi, B. (2016) 'Rapid urban growth in mountainous regions: The case of Nainital, India – UGEC Viewpoints', *Ugec Viewpoints*, (Figure 1), p. 1. Available at: https://ugecviewpoints.wordpress.com/2016/03/29/rapid-urban-growth-in-mountainous-regions-the-case-of-nainital-india/.

Annexure

Annexure 1:Rainwater Harvesting Questionnaire for Nainital Town.

Questionnaire for Rain Water Harvesting

Nainital

Ward Information

Name of Ward			**Landmark**		
Street light in the ward	Yes	No	**Provision of dustbin**	Yes	No

Type of area surrounding the ward	Residential/Industrial/Commercial/Institutional/Other

Respondent Information

Respondent Name					**Gender**	M	F	**Age**	
House	Own	Rented	**House Type**	Pakka	Semi Pakka	Kutcha	**No. of Rooms**		
No. of toilets				**Residing in town since (yr)**					

Profession	Business/Agriculture/Wage labour/ govt. Service/Self-employed/Private/other

Family Size Distribution	**Up to 18**	**19-36**	**37-54**	**55-70**	**Above 70**
Male					
Female					

Family Education Status	**Illiterate**	**Primary**	**High School**	**Inter**	**Degree & Above**
Male					
Female					

Water Amenities Services

Water Source	Piped Supply	Public tap	Bore well	Springs

Storage place for water	Tanks	Gallons	Drums	Cans
Storage capacity (litres)	20-50	50-100	100-500	>500
How often do storage water gets replaced	Once	Twice	Thrice	More than Thrice

What things have changed related to water in recent years	High	Moderate	Low
Are you satisfied with the water services	Full Satisfaction	Partial	Not at All

Piped Water Service

Frequency of supply	Once	Twice	24 Hours

Timing of supply	Morning	Evening	Both (Morning &Evening)	24 Hours

Hours of supply(daily basis)	1 Hour	2 -3 hours	More than 3 Hours
How many hours of supply is required/ sufficient	1 Hour	2 -3 hours	More than 3 Hours
Is received quantity adequate	Satisfied	Partially Satisfied	Not Satisfied

Do the pipe leak	Frequently	Rarely	Never
Do taps leak	Frequently	Rarely	Never

Water Availability	Increase in Supply	No Change	Decrease in supply
What are the methods used to cope up with water scarcity	Borewell	Springs	Gallons/ Tankers

Rate the current water supply service	quantity	color	taste	odor	pressure	maintenance
Give rating out 5. (where, 5-Excellent to 1-Bad)						

Water Quality (Springs (Dhara)/Borewell)

Factors	**Quantity**	**Taste**	**Odor**	**Color**	**Maintenance**
Give rating out 5. (where, 5-Excellent to 1-Bad)					

Water Economics

Do you pay for water	Yes	No
How is water charged	Metered Bill	Flat Rate

Type of bill	Yearly	6months	Quarterly	Monthly

Monthly expense on water (Rs)	Below 100	100-500	More than 500
Are you satisfied with bills	Yes	Charges should be minimal	No Charges

Does water bill change with season	Yes	Depends upon supply	No

Which season has highest water bill	Spring (February-April)	Summer (May-July)	Autumn (August-October)	Winter (November-January)

Does the cost increased in recent years	Yes	No
Do you pay for using borewell/Springs (Dhara)/hand pump	Yes	No

Rain Water Harvesting

Rooftop Area	

Benefits of Rainwater Harvesting Structure (From 1-	Factors	Priority (1-4)
	1. Environment	
	2. Water Security	

Most Important to 4-Least Important)	3. Extra Water Requirement (if supplied water isn't sufficient)	
	4. Saving Water Resource	

Does rooftop have any contaminants	Leaves	Twigs/Bushes	Leaves	Metal Scraps
Rooftop Material (Choose any 1)	Concrete	Asbestos Sheet	Galvanized Iron (Tin) sheets	Tiles

Are you aware of the additional cost for installation of RWH structure?	Yes	No, not aware of the cost of Installation.	May Be, don't have a clear idea about it.
Does government help in installation of Rain Water Harvesting Structure?	Yes	No, government isn't promoting such schemes.	Not Aware of such Schemes

Opinion about rain water harvesting	Efficient to Re-Use Water	Moderate to resolve water related issues.	Never thought about it.

Any water-saving practiced in the household	Yes	No	If yes, please specify:

Are you willing to spend money in future for RWH?	Yes	No	Partially with Government help.

Are you aware of any NGO working in your town for Rain Water Harvesting Structure?	If yes, provide the name:

Any Awareness program by Government or NGO's to promote Rain Water Harvesting?	Newspaper	Banners/Hoardings/	Canopies/Ads	No Promotion

Annexure 2: Rainwater Harvesting Structure Cost Calculation.

RWH Material Cost			
Material	Specification	Quantity	Amount
Storage Tank	2000 litre	3	27000
Inlet Pipe	4 inch	6m	1000
Gutter	4 inch	1	300
Elbow	4 inch	1	200
T Joint	4 inch	1	300
Gate Valve	4 inch	1	1000
Fitting	4 inch		1500
Gate Valve	2 inch	3	1800
Connecting Pipe	2 inch	6m	2000
Transport			3000
Total Cost			38100
Platform Cost			
Material	Specification	Quantity	Amount
Bricks		300	2250
Cement		2 Bag	700
Sand		Half Dumper	2500
Transport			3000
Total			8450
Labor Cost			
Man Power	Specifiction	Pax	Amount
Labor	RWH Construction	1	600
Plumber	Fitting	1	700
Supervisor	RWH Supervisor	1	2000
Total			3300
For 2 Days			6600
Labor Cost Platform			
Man Power	Specifiction	Pax	Amount
Labor	Platform Construction	1	600
Mason	Platform Construction	1	750
Supervisor	Platform Construction	1	2000
Total			3350
Total RWH COST (Commissioning)			56500
10% Contingency			5650
Grand Total			62150