

*Full Length Research.*

# Phytoremediation Technique For Recharging of Water Body: A Case Study.

**Dr. N.G.Shrivastava**

Senior Expert/Consultant, Research Monitoring and Outreach Division. National Institute of Hydrology, Roorkee, India.

Author's E-mail: [gopalshri@hotmail.com](mailto:gopalshri@hotmail.com)

**Accepted 17<sup>th</sup> September, 2017**

The alarming rise in world population and its' boundless basic needs contribute indirectly to the degradation of water resources worldwide. Depletion of vegetation cover, pollution of water from different sources, soil erosion and recession of water table has become common in many catchments. The nature has been generous in bestowing the region with bounty of water resources in form of rainwater but in the absence of scientific management of these vital resources from rain and consequent surface flow and underground storages, the water resources go waste and creates havoc downstream. Much of the enormous water resources remain unutilized and most of the natural ponds and lakes are getting dried up due to absence of proper water resource planning and scientific management. Therefore environmental friendly and cost effective be adopted for augmentation of ground water resources to revive and rejuvenate seasonal into perennial water body. The present study is based on the concept that due to Cohesive Tension capillary movement of water from Water Table to Soil and Soil To plant is maintained in nature. Only required quantity of water remains in the plant cell and remaining water quantity enhances the Soil Moisture Conditions around the root zone. This is varying from species to species due to their morphological, anatomical and physiological features which is established in the present study and accordingly Rand D work conducted for determination of required density of identified plant species at a project site so that more than 100% Soil Moisture level could be achieved for the water recharge into the stream or low lying areas. The present study was conducted in natural and manmade structures/methods of water recharge in 25 km<sup>2</sup> of Bhaktura Spring located in Bhimtal at Latitude.79<sup>o</sup>.22.41'N and Longitude E 79<sup>o</sup>.32.07' at 1000 to 1600 m altitude in 25 kms radius of Nainital District. The study was conducted for four and a half years from November, 2009 – May'2013 in 25 Km<sup>2</sup> in natural Forest Conditions.

**Keywords:** Phytoremediation Technique, Recharging of Water Body

## INTRODUCTION

Water is indispensable to all life on earth. However, fresh water is constantly formed newly through a phenomenon known as hydrological cycle. Stream, River and Ground water recharge is the process by which water percolates down the soil and reaches the water table, either by natural or artificial methods. Here, natural water recharge is dealt with. Quantification of the rate of natural water recharge is a pre-requisite for efficient water resource management. It is particularly important in regions with large demands for water supplies, where such resources are the keys to economic development. However, the rate of aquifer recharge is one of the most difficult factors to measure in the evaluation of water resources. Estimation of recharge, by any method is normally subject to large uncertainties and errors. In this paper, natural methods of water recharge are outlined.

The present study is based on the concept that due to Cohesive Tension capillary movement of water from Water Table to Soil and Soil To plant is maintained in nature. Only required quantity of water remains in the plant cell and remaining water quantity enhances the Soil Moisture Conditions around the root zone. This is varying from species to

species due to their morphological, anatomical and physiological features which is established in the present study and accordingly Rand D work conducted for determination of required density of identified plant species at a project site so that more than 100% Soil Moisture level could be achieved for the water recharge into the stream or low lying areas.

## METHODOLOGY

The present study was conducted in natural and manmade structures/methods of water recharge in 25 km<sup>2</sup> of Bhaktura Spring located in Bhimtal at Latitude.79<sup>0</sup>.22.41'N and Longitude E 79<sup>0</sup>.32.07' at 1000 to 1600 m altitude in 25 kms radius of Nainital District. **Figure 1 and 2.**

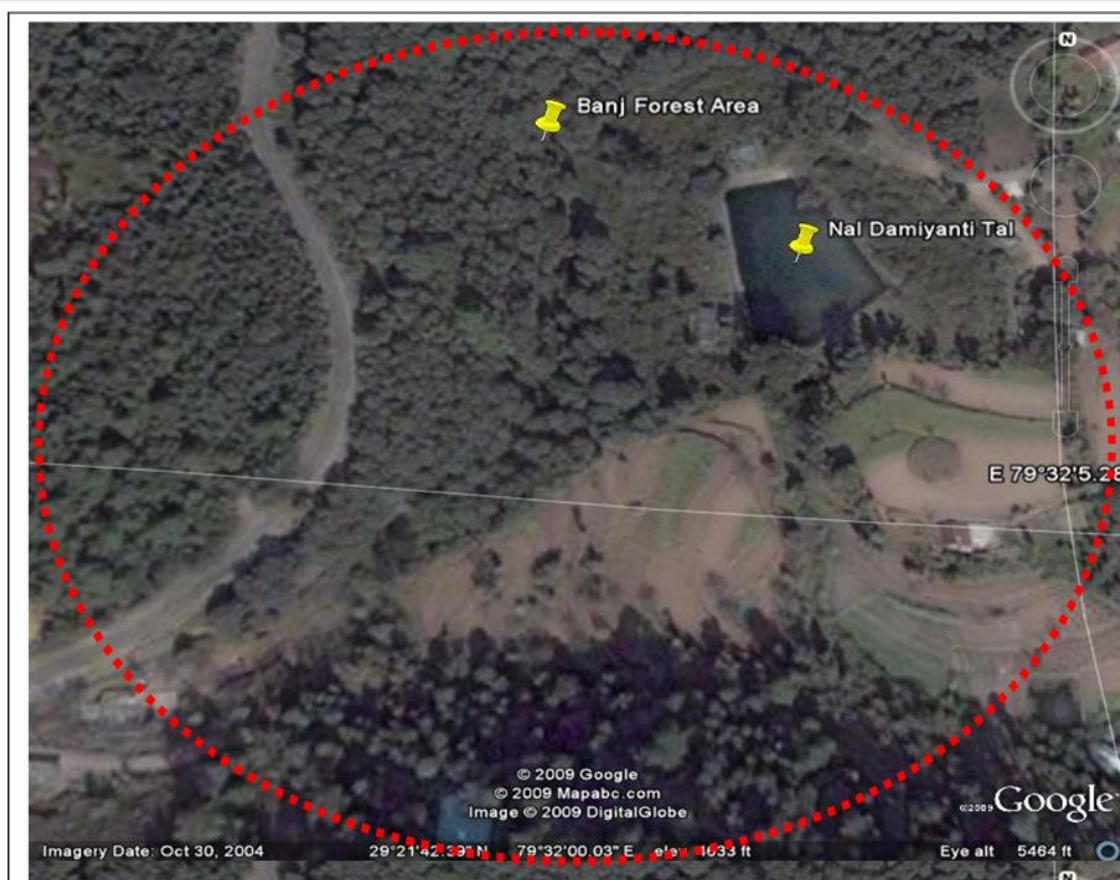
### Project Study Area Mehragaon, Bhimtal

The project site is located at Bhaktura Spring, Mehragaon. Mehragaon is a Tourist Village .It is situated in Mid of All Lakes .Sattal 5 km, Bhimtal 5 km, Naukuchital 11 km, Nainital 16 km. .Mehragaon is Surrounded by Mountains from all direction its a sort of small valley. In the North is Ghorakhal Mountain. East is Karkotak Mountain. West is Harshin Mountain.

**Ghorakal** is the place situated in the Nainital district of the Uttarakhand state of India. Ghorakhal means pond for water to horses. It is the picturesque site at the height of more than 2000 mts. It is situated near Bhowali. The source of Naldmyanti Tal is Ghorakhal Spring which is located above the Naldamyanti Tal at 2000 mts at 29°24'0"N 79°28'7"E.

The study was conducted for four and a half years from November, 2009 - May'2013 in 25 Km<sup>2</sup> in natural Forest Conditions considering following facts:

The survey of selection of experimental site was done on the basis of actual site survey keeping following requirements of experiments:



**Figure 1** : Study Area in Bhwal Range Forest, Bhimtal, District Nainital

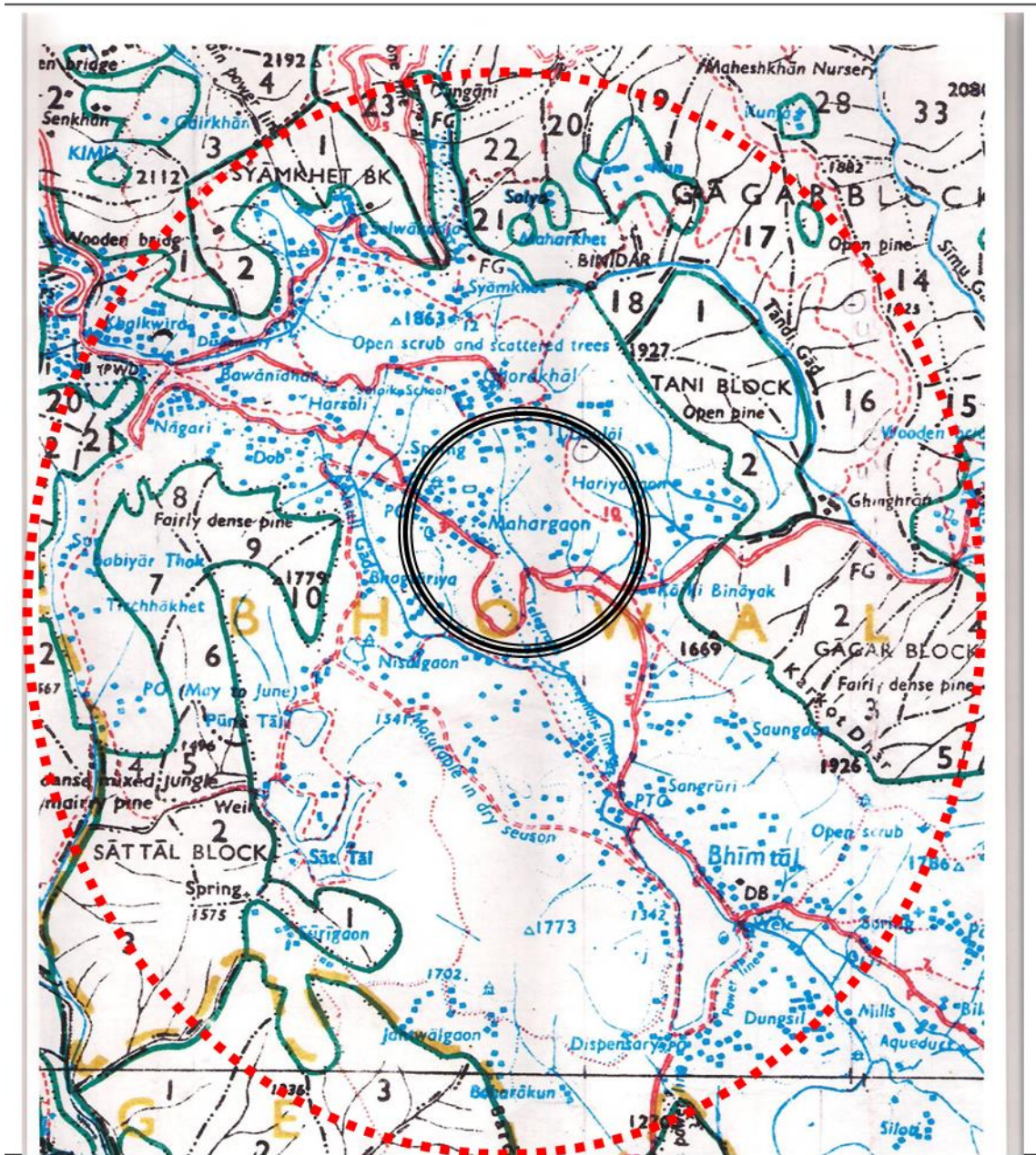


Figure 2: Study Area in Bhowali Range Forest, Bhimtal, District Nainital

1. There should be evergreen natural Forest condition at site
2. Presence of Perennial natural springs as an indicator of Water Recharging from high altitude to low altitude
3. One source of spring at high altitude and its connectivity with low altitude
4. Average age of plant species in different types of forest conditions should be uniform
5. Ideal location of setup of Check Dam for monitoring of Soil Moisture due to it percolation of water.
6. Composition of Herbs, Shrubs and Trees throughout the study period.
7. Protection and Security of Equipment setup for experiment throughout the study period.

### Survey and Identification of Forest Types at Project Area

As per Nainital Forest Management Action Plan for Bhowali Range (1998-2008), the following types of Forest exist within project site (Table 1).

**Table 1:** Type of forest for Bhowali Range

SN	Local Name	Botanical name	Latitude	Longitude	Altitude(meter)
1	Banj (Oak)	<i>Quercus leucotricophora</i>	N.29°21.797'	79°32.075'	1400
2	Chir (Pine)	<i>Pinus roxburghii</i> sargent	N.29°21.631'	79°31.963'	1200
3	Garud	<i>Olea glandulifera</i>	N.29°21.663'	79°31.777'	1300
4	Mehal	<i>Pyrus pashia</i>	N.29°21.655'	79°31.914'	1000
5	Putali	<i>Acer laevigatum</i> , Wall	N.29°21.355'	79°31.706'	1300
6	Guant	<i>Giant arborvitae</i>	N.29°21.660'	79°31.949'	1200
7	Uttis	<i>Alnus nepalensis</i>	N.29°22.115'	79°33.715'	1600
8	Kanoul/Kanchnar	<i>Bauhinia purpurea</i> , Linn	N.29°21.672'	79°31.826'	1300

### Soil Moisture Monitoring Stations at Site

As per the environmental conditions existing at project site the Automatic Soil Moisture Meter consists of Meteorological Parameters (Air Temperature, Soil Temperature, Relative Humidity, Rainfall, Wind Direction, Wind speed along with one Soil Moisture Sensor was installed at one site in Oak (Banj) Forest Area, whereas 7 others Soil Moisture Sensors has been installed at different other 7 types of existing Forest types for 4 seasons.(Post Monsoon, Winter, Summer and South-West Monsoon) for Four years and half (August 2009 to July 2014) at different depth around Root Zone of Each Plant species selected for continuous monitoring of Effective zone of Soil Moisture due to each species. The continuous Monitoring of Soil Moisture for every one hours interval at 2,4 ,8 and 10 feet depth around all the 8 types of Plant species for Post Monsoon , Winter, Summer and South-West Monsoon for Four and a half years.

The Soil Sensors has been inserted in Root Zone of each type of plant species. For online monitoring in each 1 hrs intervals during day and night.

### Water Sample Collection and Analysis

Experimental studies for Soil-Water and Plant Species Interaction with the following parameters for the identified plant species were carried out:

- Meteorological Condition:** Temperature, Rainfall, Humidity, Moisture
- Physical and Chemical Soil properties:** Porosity, Soil Texture, Soil Moisture, Conductivity, Cation and Anion
- Plant Analysis:** Rate of Water Absorption, Rate of Water Discharge, Morphological, Anatomical and Physiology of Plant (Transpiration Rate)
- Measurement of Water recharge quantity in stream, Hand Pump based Deep Well and Tube well.
- Analysis of Water Samples** All the parameters as per IS 10500 were Analyzed as per the Standard Methods (APHA, 2000)

**Infiltration Rate of Soil.:** The infiltration rate of different kinds of Soil were measured by using Double Ring Infiltrimeter installed at site .

The Weather conditions for Air Temperature, Soil Temperature, Wind Velocity, Wind Direction, Rain Fall and Relative humidity are monitoring with online monitoring system.

### Anatomical Study of Identified Plant Species:

The anatomical study of Tracheal System of Identified Plant species was done as per the Methods given in Modern Practical Botany (Volume II) S.Chand and Company Publication 2005.

### Average Percent of Water Retain in Identified Plant Species in Sandy Soil at Project Site:

The average percentage of water retention in Soil was compiled and the observed values are recorded

### Calculation of Optimum Density of Plant Species for Water Recharge.

The space-time statistical structure of soil water uptake by Identified trees is observed on the basis of:

- Root Density (by Core Sampler)
- Canopy Width (Sexton Method)

**Construction of Check Dam**

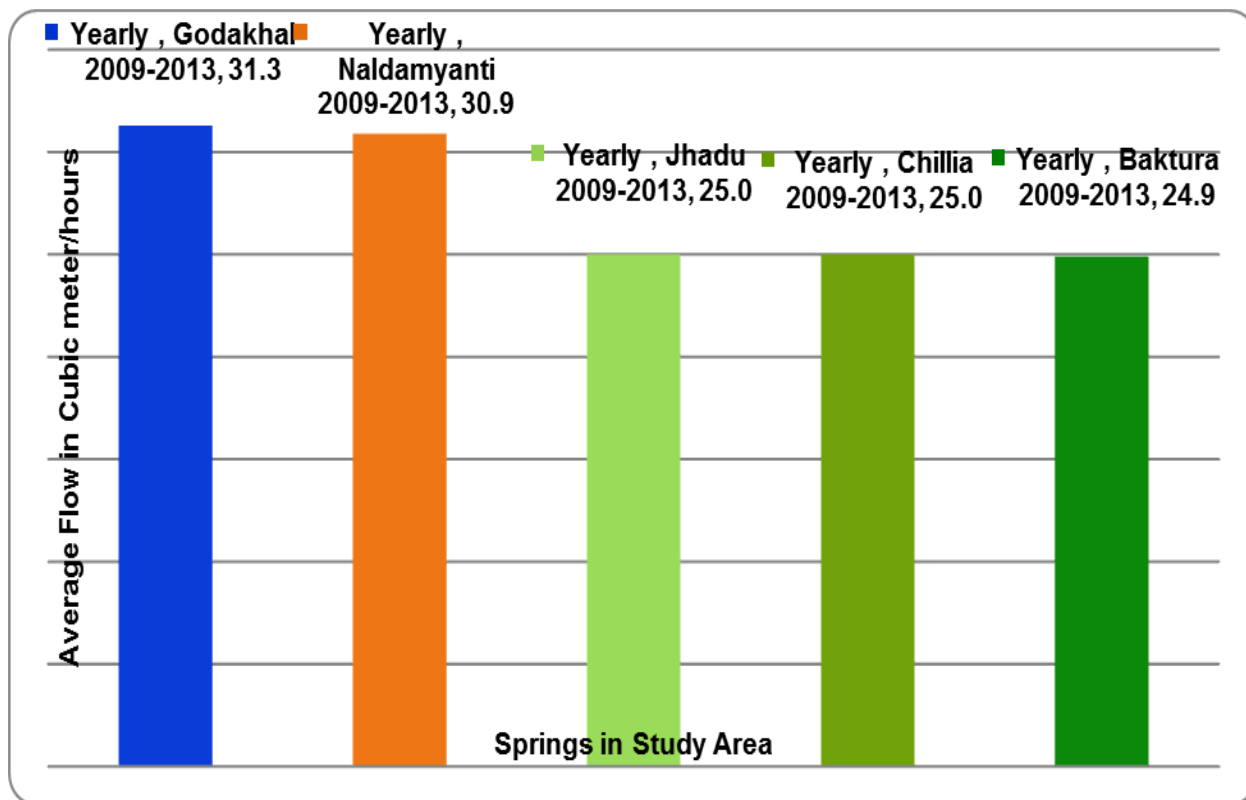
To Measurement of engineering impacts for soil moisture conditions between Check Dam and different Vegetative covers, the check dam was constructed at suitable site at Bhagtura spring downstream:

**RESULTS AND DISCUSSION**

The following three major natural springs existed in project area around Baktura site in 25 kms radius from 2000 meter altitude to 1400 meter altitude:

- a. Godakhal Spring
- b. Naldamyanti Tal Spring
- c. Baktura consists of Jhadu and Chillia

It is seen from the Figure 3 and Table 2 that the average flow of water from Godakhal was maximum 31.3 m<sup>3</sup>/hours then it is decreases in subsequent springs at Naldamyanti 30.9 m<sup>3</sup>/hr, Jhadu and Chillia 25 m<sup>3</sup>/hr and Baktura 24.9 m<sup>3</sup>/hr during 2009 to 2013. This trend indicates that there is marginal difference in the flow but it is evident that the flow is more or less maintained uniform throughout the year which may be due to dense forest and the different plant species existing in the study area and helping in recharging of water and maintaining more or less uniform water availability in these springs.



**Figure 3:** Trend in Three Years Average Flow in Different Springs at Study Area (in m<sup>3</sup>/hr 2009-2013)

**Table 2:** Trend in Three Years Average Flow in Different Springs at Study Area (in m<sup>3</sup>/hr 2009-2013)

Springs	Year	Flow m <sup>3</sup> /hr
Godakhal	2009-2013	31.3
Naldamyanti	2009-2013	30.9
Jhadu	2009-2013	25.0
Chillia	2009-2013	25.0
Baktura	2009-2013	24.9

### Establishment of Connectivity of Different Springs: in Study Area:

Watershed hydrology is a field of study that concerns itself with questions of where water goes when it rains, what flow paths the water takes to the stream, and how long water resides in the watershed. Even though these questions seem basic and water-focused, they often form the underpinning for questions of water availability, biogeochemical cycling, microbial production, and other ecological processes that depend on the water cycle. While stable isotopes of water (e.g.,  $1\text{H}^2$ ,  $^{18}\text{O}$  and  $1\text{H}^2\text{H}^{16}\text{O}$ ) have been used to study global-scale water cycling since the early 1950s (Epstein and Mayeda 1953; Craig 1961; Dansgaard 1964), they were not used for watershed-scale problems of water source, flowpath, and age until the 1970s (Dincer et al. 1970). Sklash and Farvolden (1979) were among the first hydrologists to quantify the composition of stream water and its temporal and geographical sources using water isotopes in small watersheds. Since then, watershed-scale stable isotope hydrology has blossomed (Kendall and McDonnell 1998), and today, stable isotopes are a standard tool for helping hydrologists understand the basic functioning of watersheds. More importantly, stable isotope tracing and analysis forms an important link between hydrological and ecological processes at the watershed scale where knowledge of flow path, water source, and age inform many water-mediated ecological processes.

The connectivity of each of these springs was established by isotopic analysis of Water Quality. The results are given in **Table 3**.

It seen from the **Table 3** and **Figure 4** that the:

1. In Godakhal Spring Water  $\text{O}^{18}$  was recorded  $\delta\text{‰}$  -8.69 and dD was  $\delta\text{‰}$  -59.9 during analysis of water Quality.
2. In Naldamyanti Spring Water  $\text{O}^{18}$  was recorded  $\delta\text{‰}$  -8.70 and dD was  $\delta\text{‰}$  -59.91 during analysis of water Quality.
3. In Baktura Spring Water  $\text{O}^{18}$  was recorded  $\delta\text{‰}$  -9.14 and dD was  $\delta\text{‰}$  -63.54 during analysis of water Quality.

With micro isotopic analysis of sub springs it is observed that:

- In Outlet of Godakhal Spring which is Inlet of Naldamyanti Spring Water  $\text{O}^{18}$  was recorded  $\delta\text{‰}$  -8.63 and dD was  $\delta\text{‰}$  -60.67 during analysis of water Quality.
- In Mid of Naldamyanti Tal Water  $\text{O}^{18}$  was recorded  $\delta\text{‰}$  -8.68 and dD was  $\delta\text{‰}$  -59.95 during analysis of water Quality.
- In Outlet of Naldamyanti Spring which is inlet of Jhadu Spring Water  $\text{O}^{18}$  was recorded  $\delta\text{‰}$  -8.78 and dD was  $\delta\text{‰}$  -59.10 during analysis of water Quality.
- In Chillia Spring Water  $\text{O}^{18}$  was recorded  $\delta\text{‰}$  -9.09 and dD was  $\delta\text{‰}$  -64.25 during analysis of water Quality.
- In Baktura Spring which is combination of Jhadu and Chillia Spring Water  $\text{O}^{18}$  was recorded  $\delta\text{‰}$  -9.14 and dD was  $\delta\text{‰}$  -63.54 during analysis of water Quality

It is therefore concluded that:

- *Water Quality of Ghodakhal spring, Naldamayanti Tal more or less similar to Baktura Spring.*
- *It is indicated that the water quality of Baktura spring is a combination of other source of spring also.*
- *Hence it is indicated that the source of Baktura Spring is connected with Godakhal and Naldamyanti Tal Springs.*

### Water Quality of Existing Water Resources in Study Area

There is no Well in project area. The source of Drinking Water is spring only. The samples were collected from following sampling locations for assessment of existing water quality since these are the source of drinking water in Bhagtura Village and nearby villages.

1. Godakhal Spring
2. Naldamyanti Tal
3. Chillia Gadhera
4. Jhadu
5. Bhaktura
6. Hand Pump

The Water Quality of project area was analysed and assessed, It is found that all the parameters were found well within permissible limit while compared with IS 10500.

**Infiltration rate of Soil in Study Area**

The infiltration of water into the sand is faster than into the clay. The sand is said to have a higher infiltration rate.

The infiltration rate of a soil is the velocity at which water can seep into it. It is commonly measured by the depth (in mm) of the water layer that the soil can absorb in an hour.

It is seen from the Table 3 that:

The Infiltration rate of Soil ranged from 12 to 31 with an average 25 mm/hours. The Maximum rate was observed during winter whereas minimum was during SW Monsoon during 2009-10.

The Infiltration rate of Soil ranged from 21 to 29 with an average 25 mm/hours. The Maximum rate was observed during summer and post monsoon whereas minimum was during winter during 2010-11.

The Infiltration rate of Soil ranged from 24 to 32 with an average 28 mm/hours. The Maximum rate was observed during SW monsoon whereas minimum was during summer during 2009-10.

The Infiltration rate of Soil ranged from 21 to 29 with an average 25 mm/hours. The Maximum rate was observed during SW monsoon whereas minimum was during summer during 2009-10.

An infiltration rate of 25 to 28 mm/hour means that a water layer of 15 mm on the surface of the soil will take one hour to infiltrate.

While comparing with a range of values for infiltration rates as given below as given by Natural Resources Management and Environment Department, FAO - FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS in Training Manual on Irrigation Water Management: Introduction to irrigation. The infiltration rate of sandy Clay Soil is lying between the Low to medium infiltration rate. This indicated that water retention capacity of project area is good.

Low infiltration rate	less than 15 mm/hour
medium infiltration rate	15 to 50 mm/hour
high infiltration rate	more than 50 mm/hour

Table 3: Infiltration Rate of Sandy Clay Soil at Project Area

Year	Winter Season			Summer Season				SW Monsoon			Post Mon.		Average
	Dec	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	
2009-10	24	31	30	28	26	27	17	23	12	26	30	24	25
2010-11	28	24	21	22	22	29	28	27	23	22	22	29	25
2011-12	30	28	30	24	25	28	28	32	31	30	26	25	28
2012-13	26	26	24	28	22	24	21	24	22	29	26	25	25

**Soil Moisture around Identified Plant Species in Natural Forest**

It is seen from the Table 4 that

1. The Average yearly variation in Soil Moisture around root zone of Banj Tree ranged from 71.45 cb in 2011 to 202.58 cb in 2013 with an average of 106.72 cb whereas the percentage of water Content ranges from 18.7 % in 2013 to 23% in 2010 and 2011 with an average of 21.70%.
2. The Average yearly variation in Soil Moisture around root zone of Chirj Tree ranged from 71.15 cb in 2011 to 202.92 cb in 2013 with an average of 113.01 cb whereas the percentage of water Content ranges from 18.7 % in 2013 to 23.0% in 2011 with an average of 21.42%.
3. The Average yearly variation in Soil Moisture around root zone of Garud Tree ranged from 68.42 cb in 2011 to 115.47 cb in 2013 with an average of 89.57 cb whereas the percentage of water Content ranges from 21.0 % in 2013 to 23.2% in 2011 and 2012 with an average of 21.42%.
4. The Average yearly variation in Soil Moisture around root zone of Mahal Tree ranged from 72.16 cb in 2012 to 165.57 cb in 2013 with an average of 105.89 cb whereas the percentage of water Content ranges from 19.5 % in 2013 to 22.9% in 2012 with an average of 21.62%.

5. The Average yearly variation in Soil Moisture around root zone of Putali Tree ranged from 67.36 cb in 2010 to 178.90 cb in 2013 with an average of 93.68 cb whereas the percentage of water Content ranges from 19.2 % in 2013 to 23.2% in 2010 and 2011 with an average of 22.18% .
6. The Average yearly variation in Soil Moisture around root zone of Gaunt Tree ranged from 1.24 cb in 2011 to 164.33 cb in 2012 with an average of 75.85 cb whereas the percentage of water Content ranges from 19.5 % in 2012 to 39.8% in 2011 with an average of 26.08%.
7. The Average yearly variation in Soil Moisture around root zone of Uttis Tree ranged from 33.16 cb in 2009 to 162.94 cb in 2013 with an average of 74.72 cb whereas the percentage of water Content ranges from 19.6 % in 2013 to 26.2% in 2009 with an average of 23.02%.
8. The Average yearly variation in Soil Moisture around root zone of Kachnar Tree ranged from 46.89 cb in 2009 to 162.94 cb in 2013 with an average of 85.02 cb whereas the percentage of water Content ranges from 19.6 % in 2013 to 24.7% in 2009 with an average of 22.66%. at 10 ft depth of soil.

**Table 4:** Yearly Average of Soil Moisture and Water Contents of Identified

Year	Banj		Chir		Garud		Mahel		Putali		Uttis		Kachnar	
	SM (cb)	Ave % WC	Ave	Ave % WC	Ave	Ave % WC	Ave	Ave % WC	Ave	Ave % WC	Ave	Ave % WC	Ave	Ave % WC
2009	95.81	21.8	126	20.6	115.5	21.0	139.6	20.2	77.87	22.6	33.16	26.2	46.89	24.7
2010	72.06	23.0	86.5	22.2	80.05	22.5	75.19	22.8	67.36	23.2	54.3	24.1	58.44	23.8
2011	71.45	23.0	71.2	23.0	68.42	23.2	76.96	22.7	68.61	23.2	47.29	22.5	80.9	22.5
2012	91.72	22.0	78.4	22.6	68.43	23.2	72.16	22.9	75.66	22.7	75.93	22.7	75.93	22.7
2013	202.58	18.7	203	18.7	115.5	21	165.6	19.5	178.9	19.2	162.9	19.6	162.94	19.6
<b>Average</b>	<b>106.72</b>	<b>21.7</b>	113	21.42	<b>89.57</b>	<b>22.18</b>	<b>105.9</b>	<b>21.62</b>	93.68	22.18	74.72	23.02	<b>85.02</b>	<b>22.66</b>

#### Yearly Variation in Soil Moisture (cb) and Percentage of Water Content around Check Dam

The Average yearly variation in Soil Moisture around root zone of Check Dam ranged from 27.44 cb in 2009 to 166.66 cb in 2013 with an average of 87.83 cb whereas the percentage of water Content ranges from 19.5 % in 2013 to 26.9% in 2009 with an average of 22.76% .

**Table 5:** Yearly Variation in Soil Moisture (cb) and Percentage of Water Content (% WC) around Check Dam During 2009-2013

Year	Ave	Ave % WC
2009	27.44	26.9
2010	69.13	23.1
2011	86.39	22.2
2012	89.52	22.1
2013	166.66	19.5
<b>Average</b>	<b>87.83</b>	<b>22.76</b>

#### Assessment of Water Recharge Capacity of Identified Plant Species in Project Area, Bhimtal:

##### *Water Retention capacity of Identified Plant Species*

The anatomical studies of Tracheal System of Identified Plant species were done. The Results observed are given below:

It is seen from the **Table 6** and **Figure 4** that

A. The percentage of water retention around Root Zone of **Gaunt Tree** is first highest 25.25% and Soil Moisture 41.36 cb when the Length of a Septum wall is 0.45  $\mu\text{m}$  and the width is 0.12 $\mu\text{m}$  in comparison to other identified plant species in the study area.



B. The percentage of water retention around Root Zone of **Uttis Tree** is second highest 25.02% and Soil Moisture 43.72 cb when the Length of a Septum wall is 0.17  $\mu\text{m}$  and the width is 0.031  $\mu\text{m}$  in comparison to other identified plant species in the study area.

C. The percentage of water retention around Root Zone of **Garud Tree** is third highest 24.02% and Soil Moisture 43.72 cb when the Length of a Septum wall is 0.07  $\mu\text{m}$  and the width is 0.022  $\mu\text{m}$  in comparison to other identified plant species in the study area.

D. The percentage of water retention around Root Zone of **Putali Tree** is fourth highest 24.61% and Soil Moisture 48.27 cb when the Length of a Septum wall is 0.07  $\mu\text{m}$  and the width is 0.022  $\mu\text{m}$  in comparison to other identified plant species in the study area.

E. The percentage of water retention around Root Zone of **Mahal Tree** is fifth highest 24.54% and Soil Moisture 49.09 cb when the Length of a Septum wall is 0.13  $\mu\text{m}$  and the width is 0.024  $\mu\text{m}$  in comparison to other identified plant species in the study area.

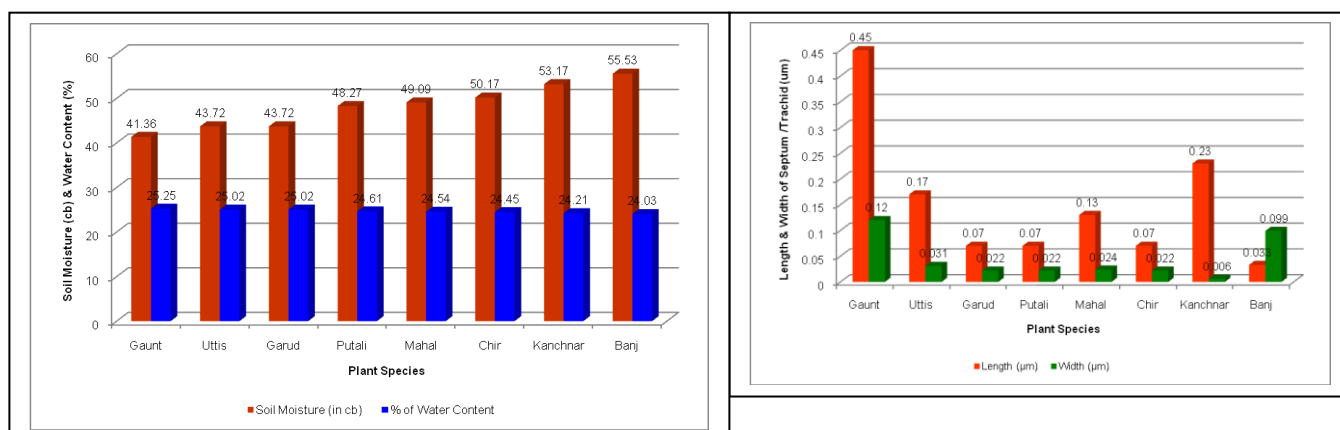
F. The percentage of water retention around Root Zone of **Chir Tree** is sixth highest 24.45% and Soil Moisture 50.17 cb when the Length of a Septum wall is 0.07  $\mu\text{m}$  and the width is 0.022  $\mu\text{m}$  in comparison to other identified plant species in the study area.

G. The percentage of water retention around Root Zone of **Kachnar Tree** is seventh highest 24.21% and Soil Moisture 53.17 cb when the Length of a Septum wall is 0.23  $\mu\text{m}$  and the width is 0.060  $\mu\text{m}$  in comparison to other identified plant species in the study area.

H. The percentage of water retention around Root Zone of **Banj Tree** is eighth highest 24.03% and Soil Moisture 55.53 cb when the Length of a Septum wall is 0.033  $\mu\text{m}$  and the width is 0.099  $\mu\text{m}$  in comparison to other identified plant species in the study area

**Table 6:** Average Length and Width of Tracheal System and Percentage of Water Content of identified plant species

SN	Plant Species	Soil Moisture (in cb)	% of Water Content	Plant Spc	Trachea Length ( $\mu\text{m}$ )	Trachea Width ( $\mu\text{m}$ )	Category
1	Gaunt	41.36	25.25	Uttis	0.450	0.120	A
2	Uttis	43.72	25.02	Kachnar	0.170	0.031	B
3	Garud	43.72	25.02	Mahal	0.070	0.022	C
4	Putali	48.27	24.61	Banj	0.070	0.022	D
5	Mahal	49.09	24.54	Chir	0.130	0.024	E
6	Chir	50.17	24.45	Garud	0.070	0.022	F
7	Kachnar	53.17	24.21	Putali	0.230	0.006	G
8	Banj	55.53	24.03	Gaunt	0.033	0.099	H



**Figure 4:** Average Length and Width of Tracheal System and Percentage of Water Content of identified Plant species

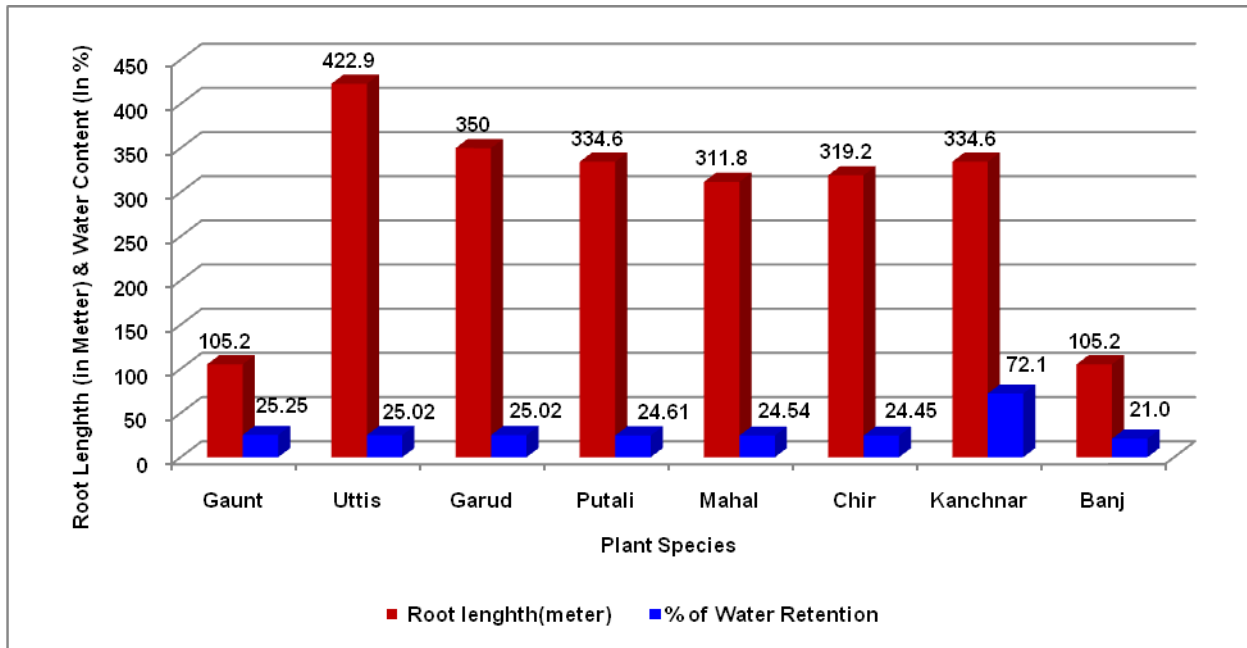
### Water Retention Capacity of Root Density of Plant Species for Water Recharge

The Root Density of Identified Plant Species was determined. The observations are given below in **Table 3.9**: It is seen from the Table 7 and Figure 5 that:

1. The Root Density of **Gaunt Tree** ranges from 1.7 to 301.9 meters from 5 to 25 cm depth with the Total Length of 105.2 meters.
2. The Root density of **Uttiis tree** ranged from 2.2 to 1251.3 meters from 5 to 25 cm depth with the Total length recoded 422.9 meter.
3. The Root Density of **Garud Tree** ranges from 1.8 to 1036.4 meters from 5 to 25 cm depth with the Total Length of 350.0 meters.
4. The Root Density of **Putali Tree** ranges from 1.6 to 991.4 meters from 5 to 25 cm depth with the Total Length of 334.6 meters.
5. The Root Density of **Mehal Tree** ranges from 1.4 to 925 meters from 5 to 25 cm depth with the Total Length of 311.8 meters.
6. The Root Density of **Chir Tree** ranges from 1.5 to 946.3 meters from 5 to 25 cm depth with the Total Length of 319.2 meters.
7. The Root Density of **Kachnar Tree** ranges from 2.1 to 1170.3 meters from 5 to 25 cm depth with the Total Length of 395.5 meters.
8. The Root Density of **Banj Tree** ranges from 2.3 to 1178.1 meters from 5 to 25 cm depth with the Total Length of 398.5 meters

**Table 7:** Root Density of Identified Plant Species at Study Area

SN	Plant Specie	Density (m/m <sup>3</sup> )			Canopy Area (M <sup>2</sup> )	Root Zone ((M <sup>2</sup> )	% of Water Retention	VolxDepthm/m <sup>3</sup>				(DepthxCanopy Area)xDensity (m/m <sup>3</sup> ) : m of roots length			Root lengthh
		5 cm	15 cm	25 cm				5 cm	15 cm	25cm	Total	5cm	15cm	25cm	
1	Gaunt) (m/m <sup>3</sup> )	10250	1475	865	3	2.3	25.25	15	34.5	525	574.5	1.7	11.9	301.9	105.2
2	Uttis (m/m <sup>3</sup> )	13050	2830	1550	3.4	2.6	25.02	17	39	1925	1981	2.2	15.2	1251.3	422.9
3	Garud (m/m <sup>3</sup> )	10020	2110	1246	3.1	2.3	25.02	15.5	34.5	1802.5	1852.5	1.8	11.9	1036.4	350
4	Putali(m/m <sup>3</sup> )	10010	1532	850	2.9	2.2	24.61	14.5	33	1802.5	1850	1.6	10.9	991.4	334.6
5	Mehal (m/m <sup>3</sup> )	10025	1735	980	2.7	2	24.54	13.5	30	1850	1893.5	1.4	9	925	311.8
6	Chir (Pine) (m/m <sup>3</sup> )	43252	23129	20433	2.8	2.1	24.45	14	31.5	1802.5	1848	1.5	9.9	946.3	319.2
7	Kachnar (m/m <sup>3</sup> )	10350	1632	925	3.3	2.5	24.21	16.5	37.5	1872.5	1926.5	2.1	14.1	1170.3	395.5
8	Banj (Oak) (m/m <sup>3</sup> )	12063	2835	1571	3.5	2.6	24.03	17.5	39	1812.5	1869	2.3	15.2	1178.1	398.5



**Figure 5:** Root Densities and Water Retention Efficiency of Identified Plant Species at Study Area

**Average Soil Moisture and Percent of Water Retention in Identified Plant Species in Sandy Soil at Project Site:**

The average Soil Moisture (cb) and percentages of water retention in Soil were observed at different depths of Root Zone are given below:

It is seen from the **Table 8** that:

1. The Average Soil Moisture ranges from 64.28 cb at 10 ft depth to 76.28 at 2 ft depth with an average of 69.59 cb whereas the percentage of Water content in root zone ranged from 24.18% at 2 ft depth to 27.84% at 10 ft depth with an average of **25.25%** in **2.3 m<sup>2</sup>** of root zone by **Gaunt Plant**. It is seen that the percentage of Water content is increasing from depth to surface which indicate that cohesive force is created during Transpiration of plant helping in uplifting of water throughout the year in uniform manner.
2. The Average Soil Moisture ranges from 48.32 cb at 10ft depth to 62.79 at 2 ft depth with an average of 55.62 cb whereas the percentage of Water content in root zone ranged from 24.26% at 2 ft depth to 26.24% at 10 ft depth with an average of **25.02%** in **2.6 m<sup>2</sup>** of root zone by **Uttis Plant**. It is seen that the percentage of Water content is increasing from depth to surface which indicate that Cohesive force created during Transpiration of plant helping in uplifting of water throughout the year in uniform manner.
3. The Average Soil Moisture ranges from 52.97 cb at 10 ft depth to 71.68 at 2 ft depth with an average of 61.93 cb whereas the percentage of Water content in root zone ranged from 23.97% at 2 ft depth to 26.99% at 10 ft depth with an average of **25.02%** in **2.3 m<sup>2</sup>** of root zone by **Garud Plant**. It is seen that the percentage of Water is increasing from depth to surface which indicate that Cohesive force created during Transpiration of plant helping in uplifting of water throughout the year in uniform manner.
4. The Average Soil Moisture ranges from 59.87 cb at 10 ft depth to 75.32 at 2 ft depth with an average of 67.90 cb whereas the percentage of Water content in root zone ranged from 23.91% at 2 ft depth to 26.10% at 10 ft depth with an average of **67.90%** in **2.2 m<sup>2</sup>** of root zone by **Putali Plant**. It is seen that the percentage of Water content is increasing from depth to surface which indicate that Cohesive force created during Transpiration of plant helping in uplifting of water throughout the year in uniform manner.
5. The Average Soil Moisture ranges from 64.33 cb at 10 ft depth to 79.91 at 2 ft depth with an average of 72.13 cb whereas the percentage of Water content in root zone ranged from 23.76% at 2 ft depth to 26.05% at 10 ft depth with an average of **24.54%** in **2.0 m<sup>2</sup>** of root zone by **Mahal Plant**. It is that the percentage of Water content is increasing from depth to surface which indicate that Cohesive force created during Transpiration of plant helping in uplifting of water throughout the year in uniform manner.

6. The Average Soil Moisture ranges from 69.62 cb at 10 ft depth to 91.45.45 at 2 ft depth with an average of 79.25 cb whereas the percentage of Water content in root zone ranged from 23.19% at 2 ft depth to 26.59% at 10 ft depth with an average of **24.45%** in **2.1 m<sup>2</sup>** of root zone by **Chir Plant**. It is seen that the percentage of Water content is increasing from depth to surface which indicate that cohesive force created during Transpiration of plant helping in uplifting of water throughout the year in uniform manner.

7. The Average Soil Moisture ranges from 57.86 cb at 10 ft depth to 70.09 at 2 ft depth with an average of 63.54 cb whereas the percentage of Water content in root zone ranged from 23.64% at 2 ft depth to 24.82% at 10ft depth with an average of **24.21%** in **2.5 m<sup>2</sup>** of root zone by **Kachnar Plant**. It is seen that the percentage of Water content is increasing from depth to surface which indicate that Cohesive force created during Transpiration of plant helping in uplifting of water throughout the year in uniform manner.

8. The Average Soil Moisture ranges from 66.46 cb at 10 ft depth to 80.11 at 8 ft depth with an average of 76.17 cb whereas the percentage of Water content in root zone ranged from 23.96% at 10 ft depth to 25.06% at 2 ft depth with an average of **24.03%** in **2.6 m<sup>2</sup>** of root zone by **Banj Plant**. It is seen that the percentage of Water content is increasing from depth to surface which indicate that Cohesive force created during Transpiration of plant helping in uplifting of water throughout the year in uniform manner.

**Table 8:** Average Soil Moisture(SM) and Percentage of Water Retention (WC) in Root Zone of Identified Plant Species in Soil (2009-2013)

SN	Plant Species	Soil Depth 2 ft		Soil Depth 4 ft		Soil Depth 8 ft		Soil Depth 10 ft		Average	
		SM (cb)	% WC	SM (cb)	% WC	SM (cb)	% WC	SM (cb)	% WC	SM (cb)	Ave % WC
1	Gaunt	76.28	24.18	71.28	24.92	66.28	26.24	64.28	27.84	69.59	25.25
2	Uttis	62.79	24.26	58.16	24.69	53.22	25.33	48.32	26.24	55.62	25.02
3	Garud	71.68	23.97	64.27	24.71	58.82	25.44	52.97	26.99	61.93	25.02
4	Putali	75.32	23.91	70.82	24.22	65.60	24.84	59.87	26.10	67.90	24.61
5	Mahal	79.91	23.76	74.44	24.23	69.83	24.83	64.33	26.05	72.13	24.54
6	Chir	91.45	23.19	81.69	24.16	74.25	25.28	69.62	26.59	79.25	24.45
7	Kachnar	70.09	23.64	64.90	24.09	61.33	24.43	57.86	24.82	63.54	24.21
8	Banj	80.11	25.06	67.76	26.35	90.36	22.93	66.46	23.96	76.17	24.03

### Calculation of Optimum Density of Plant Species for Water Recharge per hact of Land.

Based on compiled data, the optimum density of plant species per hectare is calculated and the observed values are as follows:

It seen from the **Table 9** that:

1. Each identified plant species is having different Root Density, Canopy Area, Transpiration rate which is creating cohesive force for water uplifting from Water Table to soil and plant and Water Retention Efficiency around root zone at Study Area is established with their Morphology, Anatomy and Physiological features.
2. The average water retention capacity of each identified plant species ranges from 24.03 to 25.25% throughout the year.
3. Based on the present study it is established that ideal plant density per hectare land ranges from 8 to 13 numbers. In per hectare of land around spring.
4. The categorization of best to least water recharging plant species are *Gaint arborvitae* (Gaunt)> *Alnus nepalensis* (Uttis).. > *Olea glandulifera* (Garud)> *Acer laevigatum* (Putali) > *Pyrus pashia* (Mehal) > *Pinus roxburghii* (Chir) > *Bauhinia purpurea* Kachnar> *Quercus leucotricophora* (Banj).
5. If we grow these plant species as per the range of 8-13 nos. of plant per hectare of land around the springs, there will be availability of water in spring throughout the year.

**Table 9:** Ideal Plant Density for Water Recharge (No of plant per hectare)

SN	Botanical Name	Plant Species	Cohesive Force in terms of Transpiration per plant (Ltr/year)	Canopy Area (M <sup>2</sup> )	VolxDepth(m/m <sup>3</sup> )	Root Zone (M <sup>2</sup> )	Area of Tree in Hacta	% of Water Retention	Ideal Plant Density for Water Recharge in per hectare of Land around Springs
1	<i>Gaint arborvitae</i>	Gaunt	1532.65	3.0	574.50	2.3	0.00023	25.25	9
2	<i>Alnus nepalensis</i>	Uttis	7855.11	3.4	1981.00	2.6	0.00034	25.02	13
3	<i>Olea glandulifera</i>	Garud	1671.72	3.1	1852.50	2.3	0.00023	25.02	9
4	<i>Acer laevigatum</i>	Putali	1498.02	2.9	1850.00	2.2	0.00022	24.61	9
5	<i>Pyrus pashia</i>	Mehal	3433.14	2.7	1893.50	2.0	0.0002	24.54	8
6	<i>Pinus roxburghii</i>	Chir	3131.15	2.8	1848.00	2.1	0.00021	24.45	8
7	<i>Bauhinia purpurea</i>	Kachnar	7624.08	3.3	1926.50	2.5	0.00025	24.21	10
8	<i>Quercus leucotricophora</i>	Banj	4271.55	3.5	1869.00	2.6	0.00026	24.03	10

## SUMMARY

The alarming rise in world population and its' boundless basic needs contribute indirectly to the degradation of water resources worldwide. Depletion of vegetation cover, pollution of water from different sources, soil erosion and recession of water table has become common in many catchments. The nature has been generous in bestowing the region with bounty of water resources in form of rainwater but in the absence of scientific management of these vital resources from rain and consequent surface flow and underground storages, the water resources go waste and creates havoc downstream. Much of the enormous water resources remain unutilized and most of the natural ponds and lakes are getting dried up due to absence of proper water resource planning and scientific management. Therefore environmental friendly and cost effective be adopted for augmentation of ground water resources to revive and rejuvenate seasonal into perennial water body.

The present study is based on the concept that due to Cohesive Tension capillary movement of water from Water Table to Soil and Soil To plant is maintained in nature. Only required quantity of water remains in the plant cell and remaining water quantity enhances the Soil Moisture Conditions around the root zone. This is varying from species to species due to their morphological, anatomical and physiological features which is established in the present study and accordingly Rand D work conducted for determination of required density of identified plant species at a project site so that more than 100% Soil Moisture level could be achieved for the water recharge into the stream or low lying areas.

The present study was conducted in natural and manmade structures/methods of water recharge in 25 km<sup>2</sup> of Bhaktura Spring located in Bhimtal at Latitude.79<sup>0</sup>.22.41'N and Longitude E 79<sup>0</sup>.32.07' at 1000 to 1600 m altitude in 25 kms radius of Nainital District. The study was conducted for four and a half years from November, 2009 - May'2013 in 25 Km<sup>2</sup> in natural Forest Conditions considering following facts:

The survey of selection of experimental site was done on the basis of actual site survey keeping following requirements of experiments:

1. There should be evergreen natural Forest condition at site
2. Presence of Perennial natural springs as an indicator of Water Recharging from high altitude to low altitude
3. One source of spring at high altitude and its connectivity with low altitude
4. Average age of plant species in different types of forest conditions should be uniform
5. Ideal location of setup of Check Dam for monitoring of Soil Moisture due to it percolation of water.
6. Composition of Herbs, Shrubs and Trees throughout the study period.
7. Protection and Security of Equipment setup for experiment throughout the study period.

The study established that Each identified plant ( *Gaint arborvitae* (Gaunt) > *Alnus nepalensis* (Uttis) > *Olea glandulifera* (Garud)> *Acer laevigatum* (Putali) > *Pyrus pashia* (Mehal) > *Pinus roxburghii* (Chir) > *Bauhinia purpurea* Kanchnar> *Quercus leucotricophora* (Banj)) species is having different Root Density, Canopy Area, Transpiration rate which is creating cohesive force for water uplifting from Water Table to soil and plant and Water Retention Efficiency around root zone at Study Area is established with their Morphology, Anatomy and Physiological features. The average water retention capacity of each identified plant species ranged from 24.03 to 25.25% throughout the year.

Based on the present study it is established that ideal plant density per hectare land ranged from 8 to 13 numbers of identified plant species at Hilly region. *Gaint arborvitae*, *Acer laevigatum* and *Bauhinia purpurea* can grow in plains and their density per hectare area may vary because of the variation of depth of water Table at plains which may be required to be re-established. The categorization of best to least water recharging plant species have been done from *Gaint arborvitae* (Gaunt) > *Alnus nepalensis* (Uttis) > *Olea glandulifera* (Garud)> *Acer laevigatum* (Putali) > *Pyrus pashia* (Mehal) > *Pinus roxburghii* (Chir) > *Bauhinia purpurea* Kanchnar> *Quercus leucotricophora* (Banj). If we grow these plant species as per the range 8-13 nos. of plants per hectare of land around the springs, there will be availability of water in spring throughout the year.

Phytoremediation technique of water recharging is a Cost effective technology which can help in sustainable development of environment.

## CONCLUSION AND RECOMMENDATION

The following are the conclusion and recommendation of the study conducted during 2009-2013 on “*Phytoremediation Techniques of Water Recharge – A Case study at Hilly Terrain at Nainital District*”

### Conclusion

1. The present study was conducted in natural and manmade structures of water recharge in 25 km<sup>2</sup> of Bhaktura Spring, Bhimtal region located at Latitude N 79<sup>0</sup>.22.412' and Longitude E 79<sup>0</sup>.32.065' at 1000 to 1600 m altitude in 25 kms radius of Nainital District.

2. The present R and D concept is based on the concept that due to Cohesive Tension capillary movement of water from Water Table to Soil and Soil To plant is maintained in nature. Only required quantity of water remains in the plant cell and remaining water quantity enhances the Soil Moisture Conditions around root zone. This is varying from species to species due to their morphological, anatomical and physiological features which is established in the present study and accordingly Rand D work conducted for determination of required density of identified plant species at project site so that more than 100% Soil Moisture level could be achieved for the water recharge into the stream or low lying areas.

3. The following plant species from natural forest condition were Identified and Screened for assessment of water discharge efficiency with respect to natural forest types based on their:

- Evergreen natural Forest condition at site
- Presence of Perennial natural springs as an indicator of Water Recharging from high altitude to low altitude
- One source of spring at high altitude and its connectivity with low altitude spring
- Average age of plant species in different types of forest conditions kept uniform
- Ideal location of setup of Check Dam for monitoring of Soil Moisture due to its percolation of water.
- Composition of Herbs, Shrubs and Trees throughout the study period.
- Protection and Security of Equipment setup for experiment throughout the study period.

Table

Station	Local Name	Botanical Name	Family	Average Age (Yrs)	Avr. Root Depth (Ft)	Lat/Long/Altitude
S1	Banj (Oak)	<i>Quercus leucotricophora</i>	Fagaceae	30-35	5 - 10	N.29°21.797'
						E.79°32.075'
						1400 m
S2	Chir (Pine)	<i>Pinus roxburghii</i>	Pinaceae	30-35	5 - 10	N.29°21.631'
						E.79°31.963'
						1200 m
S3	Garud	<i>Olea glandulifera</i>	Oleaceae	30-35	5 - 10	N.29°21.663'
						79°31.777'
						1300 m
S4	Mehal	<i>Pyrus pashia</i>	Rosaceae	30-35	5 - 10	N.29°21.655'
						E. 79°31.914'
						1000 m
S5	Putili(The Maple)	<i>Acer laevigatum.</i>	Sapindaceae	30-35	5 - 10	N.29°21.355'
						E. 79°31.706'
						1300 m
S6	Giant Gaunt)	<i>Giant arborvitae</i>	Cupressaceae	30-35	5 - 10	N.29°21.660'
						E.79°31.949'
						1200 m
S7	Uttis	<i>Alnus nepalensis</i>	Betulaceae	30-35	5 - 10	N.29°22.115'
						E. 79°33.715'
						1600 m
S8	Kanoul/Kanchnar	<i>Bauhinia purpurea.</i>	Fabaceae	30-35	5 - 10	N.29°21.672'
						E. 79°31.826'
						1300 m
S9	Check Dam	<i>Bhaktura Spring</i>				

4. The Flow of water in Godakhal, Naldamyanti, Baktura, Jhadu and Chillia Springs in study area with magnitude of average flow remains between 24.9 to 31.3 mm<sup>3</sup>/hrs during 2009 to 2013. This indicates that the water flow is maintained throughout the year which is more than the average flow in the selected springs.

5. Isotopic Identification of Water Characteristics of Different Main Spring Water at Study Area, Bhimtal shows that :

- Water Quality of Ghodakhal spring, Naldamayanti Tal is more and similar to Baktura Spring.
- It is indicated that the water quality of Baktura spring is a combination of other source of spring also.
- Hence it is indicated that the source of Baktura Spring is connected with Godakhal and Naldamyanti Tal Springs.

Hence water quality indicates the interconnectivity with each other.

6. The inventorisation of Water Quality was done for 2009 to 2013 for identified springs, and Hand pumps. It is indicated that **All the values found were within permissible limit as per IS 10500 and water quality is potable.**

7. The infiltration rate of Water ranged from 50.42 to 662.72 mm/hr for the Sandy, Clay or silt Soil at study area. While comparing the range of infiltration rate of different Soil types it is found that project area is having more than 50 mm/hrs which shows high infiltration rate.

As per Irrigation Water Management: Introduction to irrigation (1985) given by FAO Corporate Documentary Repository - [Natural Resources Management and Environment Department](#). **A range of values for infiltration rates is given below:**

<b>Low infiltration rate</b>	<b>less than 15 mm/hour</b>
<b>medium infiltration rate</b>	15 to 50 mm/hour
<b>high infiltration rate</b>	more than 50 mm/hour

8. The Seasonal and average Soil Moisture condition and percentage of water content in root zone of identified plant species in soil at various depths in naturally existing different types of forest conditions in study area shows that the

Soil Moisture and percentage of Water content increases from depth to surface which indicates that Cohesive force is created by Transpiration of plant helping in uplifting of water throughout the year in uniform manner.

Based on compiled data, the optimum density of plant species per hectare area is calculated and the following conclusions have been drawn:

- Each identified plant species is having different Root Density, Canopy Area, Transpiration rate which is creating cohesive force for water uplifting from Water Table to soil and plant and Water Retention Efficiency around root zone at Study Area is established with their Morphology, Anatomy and Physiological features.
- The average water retention capacity of each identified plant species ranged from 24.03 to 25.25% throughout the year.
- Based on the present study it is established that ideal plant density per hectare land ranged from 8 to 13 numbers of land around spring.
- The categorization of best to least water recharging plant species is Gaint arborvitae (Gaunt) > Alnus nepalensis (Uttis) > Olea glandulifera (Garud)> Acer laevigatum (Putali) > Pyrus pashia (Mehal) > Pinus roxburghii (Chir) > Bauhinia purpurea Kanchnar> Quercus leucotricophora (Banj).

If we grow these plant species as per the range 8-13 nos. of plant per hectare of land around the springs, there will be availability of water in spring throughout the year.

9. The naturally recharged water quality of springs and Hand pump within the project period, was found potable.

10. The ground water quality by analyzing water quality parameters like turbidity and bacteriological contamination shows that they were within the permissible limit as per IS : 10500.

11. The water recharging through Check Dam was found that it is depending upon the flow rate of springs only and is more at surface than the depth whereas natural recharging of ground water shows uniformity throughout the year.

12. The Important value Index value of Community Structure shows that the three communities of ten or Nineteen species contributed more than half the I.V.I. of the important vegetation. Dominance was shared by several species at each altitude, and, with the possible exception of Quercus leucotricophora and Alnus nepalensis plantation. No one species exerted complete dominance over any appreciable area. Importance, as indicated by I.V.I. was shared by several species. This may change from station to station as they are not necessarily the physiognomic species of the community.

## RECOMMENDATIONS

The following are the recommendations of present R and D work for Spring Development in Hilly region

1. Each identified plant species is having different Root Density, Canopy Area, Transpiration rate which is creating cohesive force for water uplifting from Water Table to soil and plant and Water Retention Efficiency around root zone at Study Area is established with their Morphology, Anatomy and Physiological features.
2. The average water retention capacity of each identified plant species ranged from 24.03 to 25.25% throughout the year.
3. Based on the present study it is established that ideal plant density per hectare land ranged from 8 to 13 numbers of identified plant species at Hilly region. Gaint arborvitae, Acer laevigatum and Bauhinia purpurea can grow in plains and their density per hectare area may vary because of the variation of depth of water Table at plains which may be required to be re-established.
4. The categorization of best to least water recharging plant species is Gaint arborvitae (Gaunt) > Alnus nepalensis (Uttis) > Olea glandulifera (Garud)> Acer laevigatum (Putali) > Pyrus pashia (Mehal) > Pinus roxburghii (Chir) > Bauhinia purpurea Kanchnar> Quercus leucotricophora (Banj).
5. If we grow these plant species as per the range 8-13 nos. of plants per hectare of land around the springs, there will be availability of water in spring throughout the year.
6. Phytoremediation technique of water recharging is a a Cost effective technology which can help in sustainable development of environment.

## ACKNOWLEDGEMENT

The Project Investigator, Pollution Control Research Institute, BHEL, Hardwar convey their deep sense gratitude, thankfulness and appreciation for the valued guidance and unstinted cooperation continuously extended by officials of Ministry of Drinking Water and Sanitation, Govt of India, New Delhi and the award of this work. Our gratitude and thanks is also due to the District Forest Department, Irrigation Department Indian Meteorological Department, Gram Panchayat and Soil Conservation Departments of Govt of Uttarakhand, National Hydrological Institute, Roorkee



and of respective places, where the present studies have been carried out for their associations and help in conducting these studies. We are also thankful to all those institutions which have directly or indirectly extended their help during the collection of data related to these studies. Investigators are thankful to BHEL Management for providing the facilities for conducting the study. Without such support it would have hardly been possible for project investigators to conduct the study smoothly and prepare of this report.

## REFERENCES

- American Public Health Association (2000) : Standard Methods For Examination of Water and Waste Water Examination, American Public Health Department
- Bischetti, G.B., E.A. Chiaradia, T. Simonato, B. Speziali, B. Vitali, P. Vullo, and A. Zocco. 2005. Root strength and root area ratio of forest species in Lombardy. *Plant and Soil* 278:11-23.
- Brower, J., Zar. J. and Von Ende. C. 1990. Field and laboratory methods for general ecology. 3rd edition, Wm.C.Publishers, Dubuque
- Bauhinia purpurea* linn.: A review of its ethnobotany, phytochemical and pharmacological profile Kumar T., Chandrashekar K.S. *Research Journal of Medicinal Plant* 2011 5:4 (420-431)
- Campbell, Neil (2002). *Biology*. San Francisco, CA: Pearson Education, Inc.. pp. 759. ISBN 0-8053-6624-5
- Calculation of Percentage of Water Content through Soil Moisture <http://cru.cahe.wsu.edu/CEPublications/pnw0475/pnw0475OP.html>
- Curtis, J. T., and McIntosh, R. P., 1951. An upland forest continuum in the prairie forest border region of Wisconsin. *Ecol.* 32: 476-496.
- Chen, Y., de Jong, P. C., and Oterdoom, H. J. *Flora of China: Aceraceae (draft)*
- Dixon, H; Joly (1894). "On the ascent of sap". *Ann. Bot.* 8: 468–470.
- Dixon, H (1914). *Transpiration and the ascent of sap in plants*. New York: Macmillian. pp. 216.
- Dixon, H (1924). *The transpiration stream*. London: University of London Press, Ltd. pp. 80.
- DeBaets, S., J. Poesen, B. Reubens, K. Wemans, J. DeBaerdemaeker, and B. Muys. 2008. Root tensile strength and root distribution of typical Mediterranean plant species and their contribution to soil shear strength. *Plant and Soil* 305:207-226.
- Danjon, F., D. Barker, M. Drexhage, and A. Stokes. 2008. Using three-dimensional plant root architecture in models of shallow-slope stability. *Annals of Botany* 101:1281-1293.
- Forest Survey of India (2005) : Report on State Forest Department  
[Forest Invasive Species: Country Report](#). Food and Agriculture Organization of the United Nations. Retrieved July 27, 2011.
- Florida Exotic Pest Plant Council (2005). "[Florida Exotic Pest Plant Council: Lantana camara](#)" (PDF). Florida Exotic Pest Plant Council. Retrieved September 19, 2007
- Floyd, Alex G. (2009). *Rainforest Trees of Mainland Southeastern Australia*. Lismore, NSW: Terania Rainforest Publishing. p. 278. ISBN 978-0-9589436-7-3.
- Floyd, Alex G. (2009). *Rainforest Trees of Mainland Southeastern Australia*. Lismore, NSW: Terania Rainforest Publishing. p. 278. ISBN 978-0-9589436-7-3.
- Gymnosperm Database: *Thuja plicata*  
<http://herbs-treatandtaste.blogspot.com/2011/04/himalayan-wild-pear-pyrus-pashia.html>. 2011 "HIMALAYAN WILD PEAR (PYRUS PASHIA) - INFORMATION, USES AND MEDICINAL BENEFITS",
- Kenasy, E (1895). "Ueber das Saftsteigen". *Bot. Cent.* 62: 237–238.
- Kanetkar and Kulkarni "A Text Book of Surveying and Leveling For Engineering Students and Practicing Engineers" Part -1 .
- Kendall, C and J.J. McDonnell (Eds.) (1998), *Isotope Tracers in Catchment Hydrology* Elsevier Science B.V., Amsterdam. pp. 51-86.
- Krause, S. et al. (2007). *Morphological biodiversity and local use of the Himalayan pear (Pyrus pashia) in Central Bhutan= Vol.54(Issue 6)*. pp. 1245–1254.
- Khanna, L. S.; Prakash, R. (1983). *Theory and Practice of silvicultural Systems*. International Book Distributions.
- Indian Standards (1992) : IS 10500: Standard for Drinking Water, BIS  
[Lantana camara](#). Integrated Taxonomic Information System (ITIS).  
[Lantana camara](#). Germplasm Resources Information Network (GRIN).
- Methods given in Modern Practical Botany (Volume II) (2005) S.Chand and Company Publication
- Moyhill Publishing (2007). "[English vs. Latin Names](#)". Moyhill Publishing. Retrieved September 19, 2007.
- Office of Economic and Stastical Offcer (2007) : Statistical Book District Nainital. Forest Development Agency Nainital (2002-2007) : Micro Planning of Forestation . Under National Forestation Plan.

- [Olea paniculata R.Br.](#)". [Australian Plant Name Index \(APNI\)](#), IBIS database. Centre for Plant Biodiversity Research, Australian Government.
- [Olea paniculata R. Brown, Prodr. 523. 1810.](#)". *Flora of China – eFloras Online*. 2008. Retrieved 2010-06-02.
- Parmar, C. and M.K. Kaushal 1982 *Pyrus pashia Buch. and Ham*", p. 78–80. In: *Wild Fruits*. Kalyani Publishers, New Delhi, India.
- Rosacia, W. Z., et al. (2004). "[Lantana and Hagonoy: Poisonous weeds prominent in rangeland and grassland areas](#)". *Research Information Series on Ecosystems* (Department of the Environment and Natural Resources, Republic of the Philippines) **16** (2). Retrieved July 27, 2011.
- Sheikh, MI (1992). *Trees of Pakistan*: 5–142 [Pyrus Pashia](#) [http://pdf.usaid.gov/pdf\\_docs/PNABW250.pdf](http://pdf.usaid.gov/pdf_docs/PNABW250.pdf)= [Pyrus Pashia](#) |url=
- The Plant List: A Working List of All Plant Species".  
"USDA GRIN Taxonomy".
- US Forest Service, Silvics Manual: [Western Redcedar](#)
- Uppadhyay, N.K. and Singh, N.K. (1998) : Nainital Circle Action Plan (Second) (1996) : Forest Management plan of Nainital Forest Department of South Kumaon Circle, Uttar Pradesh Part 1 and Part 2
- Vineyard, Jerry D.; Fender, Gerald L. (1982) [1974]. [Springs of Missouri](#) (PDF). Missouri Department of Natural Resources, Division of Geology and Land Survey. p. 12. Library of Congress Card Catalog No. 73-620125. Retrieved 2009-08-18.
- Van Gelderen, C.J. and van Gelderen, D.M. (1999). *Maples for Gardens: A Color Encyclopedia*.
- Walker, Karen; Burrows, Geoff; McMahon, Lynne (2001). [Bidgee bush : an identification guide to common native plant species of the south western slopes of New South Wales](#). Yarralumla, Australian Capital Territory: [Greening Australia](#). p. 82. ISBN 1-875345-61-2. Retrieved 21 March 2010.
- Zamani, A. et al. (2007). *PYRUS PASHIA (ROSACEAE), A NEW RECORD FOR THE FLORA OF IRAN = IRAN*. *JOURN. BOT.* **15** (1), pp. 72–75. Tehran.
- Zakaria, Z. A., E. E. Abdul Hisam, et al. (2011). "In vivo antiulcer activity of the aqueous extract of *Bauhinia purpurea* leaf." *Journal of Ethnopharmacology* **137**(2): 1047-1054.
- Williams, C. B., 1950. The application of the logarithmic series to the frequency of occurrence of plant species in quadrates. *Journal of Ecology*, **38**: 107-138.