CHAPTER 3

ENGINEERING ANALYSIS & ASSESSMENT OF EXISTING WATERMILLS

Chapter Overview

- *To identify the parameters of importance for analysis of watermills.*
- *To understand the present condition of the watermills on above identified parameters.*
- *To identify barriers, if any, in proper operation and maintenance of watermills.*
- *To analyse the existing improved watermills by carrying out lab testing.*
- *To identify areas of further improvement in existing improved watermills.*

3.1 GHARAT

Gharat (Watermill) is an old age and well known concepts in the hills of state of Uttarakhand in India. Rolling sound of continuous friction between two stones near the flowing stream symbolizes the presence of Gharat. It converts the water energy of a flowing stream into mechanical energy.

Man has always tried to exploit the hidden energy from a natural source into an energy he can harness to his advantage. To combat the harsh physical condition of hilly region he has made use of one of the natural resource available in abundance, water stream, to develop mechanical power by a device called Gharat or Watermill.

There are three types of watermills available in this region. The simplest and probably the oldest was a vertical wheel with blades/ buckets, on which the force of stream acted. Next was horizontal wheel with vertical shaft attached to it for driving the millstone. Approximately all the watermills in the region are of this type only. Third was the geared mill driven by vertical wheel with horizontal shaft. Each type of mill has its own advantages and disadvantages.

3.2 EXISTING WATERMILL

To run these mills a channel is dug along the river to carry the water up to the mill house with some gradient. The water of this channel or chute falls on the flat blades of the wheel. The water channel normally consists of an open channel either made from wooden planks or carved from a large tree trunk. It is narrowed down towards the end to form nozzle.

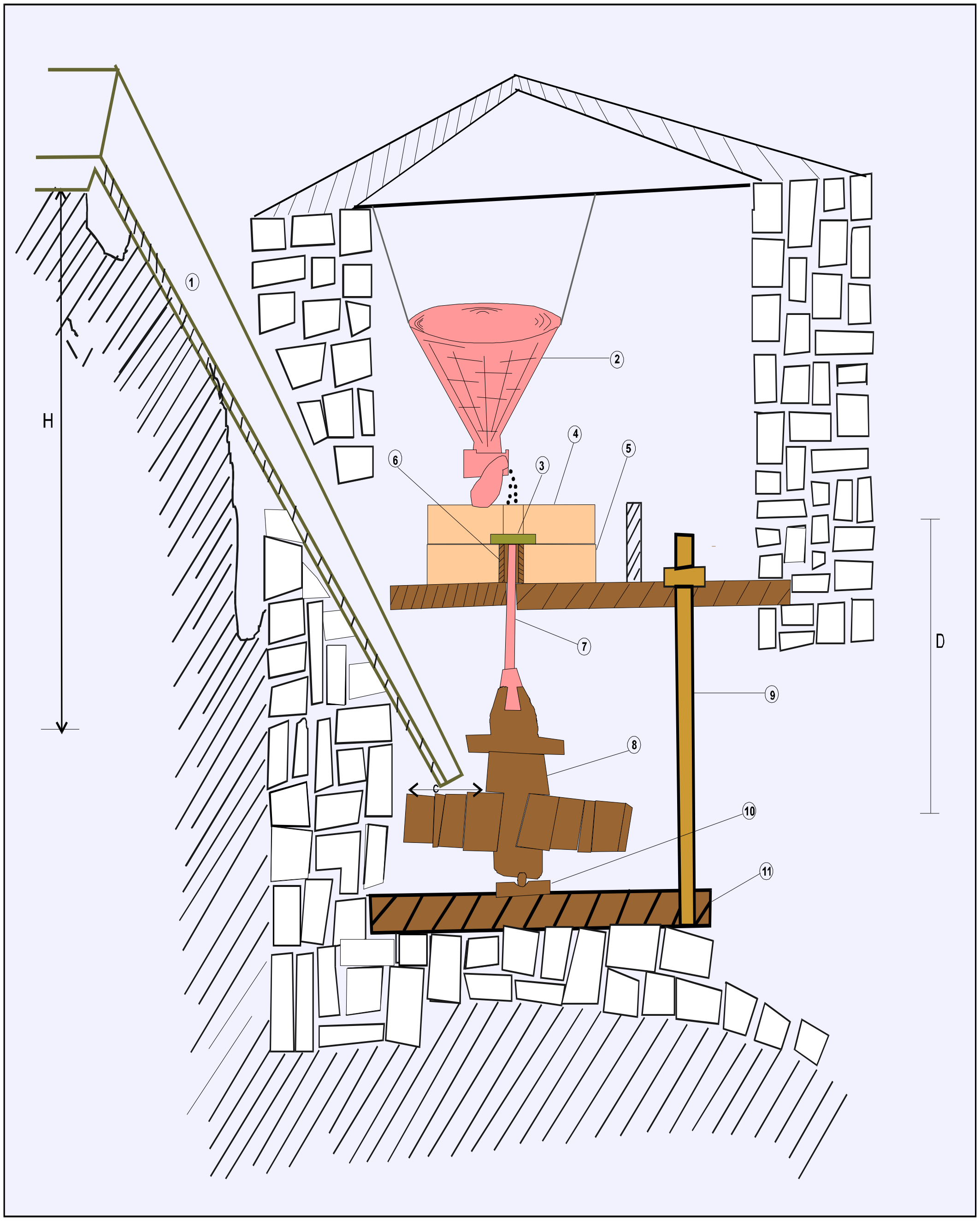
Water with some head strikes the blades and rotates the wheel, which in turn rotates the shaft and stone connected to it. The blades are also made up of wood connected to a thick vertical wooden shaft which is tapered at both end. Two round millstones, hewn locally, are fitted on top of the shaft to act as grinding mill. The wooden shaft of the wheel (turbine) is supported on a stone pivot through a pin and held in the bearing at the top. The bearing is a wooden bush fixed in the lower stationary grinding stone. The top-grinding wheel rests on the lower stone and is rotated by the wheel/ turbine shaft through a straight slot coupling. The gap between the stone is adjusted by lifting the upper stone with the help of a mechanical lever.

The blades vary in number in different gharat from 11 to 21, which is fixed lengthwise at the axis to transmit the entire load to the shaft. At opposite end from the cylindrical axis, a long shaft connects it to the upper part of the grinder stone. It is interesting to note that the fitting and quality of grain can be determined even in this nature-driven process for which a groove is made into the upper mill stone to set a tapered iron piece that holds the shaft and grinder simultaneously. The thick shaft bears the load of the system that in turn diffuses it over the horizontally laid plank. One end of the plank is attached to an adjusting lever, which moves upward and downward. The lever governs the distance between the moving and the stationary part of the grinder. An upward movement of the lever allows for coarse grinding while the downward is for fine grinding.

The main components of a gharat are listed as follows:

- Chute: A wooden drain kind of thing that routes and forces the water from the channel to the wheel blades attached to the vertical shaft.
- Grain Feeder: A bag or funnel, which feeds the grain to the millstones.
- Bearing: That helps the upper grinding stone to rotate freely.
- Upper milling stone: The circular Upper grinding stone of the mill that is directly attached to the shaft and rotates with it.
- Lower milling stone: The circular lower grinding mill stone through the middle of which the shaft rod passes to support the upper grinding stone. This lower grinding stone remains stationary.
- Bush: A round wooden piece fitted to the hole in the lower grinding stone through which the shaft rod passes.
- The vertical shaft: The wooden or iron rod that connects the rotating wheel down below with the upper grinding stone.
- Runner with hub: The thick wooden portion to which the fans are fitted and which determines the speed of the rotation of the shaft.
- Lifting mechanism lever: A wooden mechanism that determines the coarseness or the fineness of the grains being ground.
- Bearing: The point at which the pin of the shaft rests giving free rotation.

A typical conventional system looks like as follows:



(**Fig 3.1:** Conventional Watermill System)

3.3 RATIONAL FOR IMPROVEMENT IN EXISTING WATERMILL

Watermills are means of livelihood and energy in the difficult & remote terrain of hills for the ages. In spite of being low cost and locally made device, it is losing its charm and applicability. However, some of the following socio economic and environmental issues are reviving the usefulness of watermills.

- Rising concern for environment (Global warming)
- Fast depleting sources of fossil fuels
- Sustainable development through means of livelihood
- Social imbalance due to migration of rural mass to cities.
- Techno – economic constraints in extending the conventional sources of energy to far off rural habitats.

To take full advantage of the benefits offered by watermills it is imperative to understands the barriers in its effective usage. A survey was conducted to understand these barriers.

There are approximately 15449 watermills all across the state of Uttaranchal as per the data available with state renewable agency, Uttarakhand Renewable Energy Development Agency, UREDA.

A meeting was conducted at the head office of state renewable agency, Uttarakhand Renewable Energy Development Agency, UREDA, with their concerned officials, representatives of some of the district's "Self Help Groups", Village panchayat, NGOs and watermill owners to identify the parameters and methodology for survey.

Survey was conducted for approximately 10% of the watermills (1500 out of 15449 watermills) all across the state covering the entire geographical region. List of block wise watermills surveyed is as per annexure. Survey was conducted through representatives of self help, village panchayats and society of watermill owners. Survey was arranged by UREDA and coordinated by its officers in all 13 districts. Survey format is attached as Appendix A.

3.4 PRESENT CONDITION OF WATERMILL

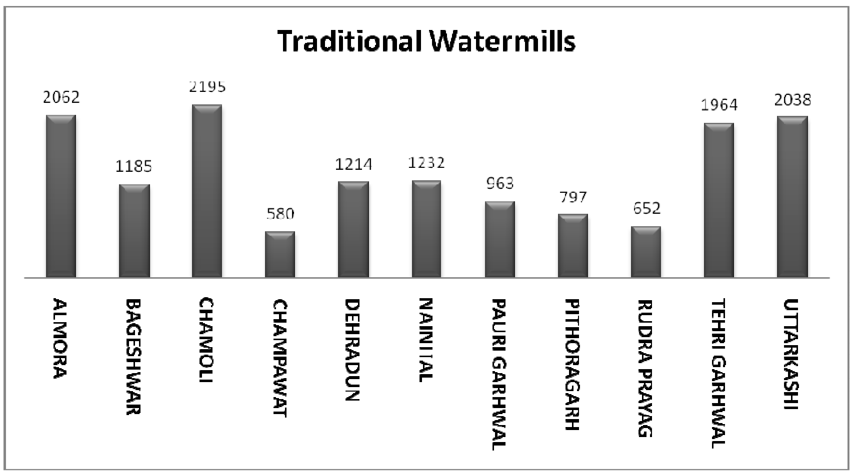
Present condition of the watermill can be analysed based on the following points:-

1. Present Status of watermill
2. Current usage (Electrical/mechanical)
3. Working condition of watermill
4. Working duration (annual)
5. Potential for upgradation of watermill
6. Distance of watermill from village
7. Distance of watermill from road
8. Status of Electrification
9. Annual average discharge
10. Available head
11. No. of mills within 1 km
12. No. of households within 500 Mtrs
13. Reason for watermill not functioning
14. Willingness for modification of watermill.

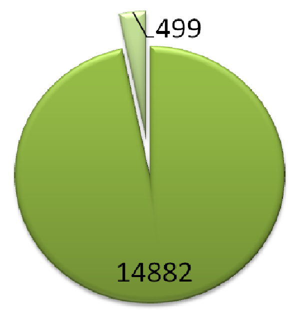
3.4.1 Present Status of Watermill

a. Traditional Watermill

The state of Uttaranchal is enriched with more than 15000 numbers of watermills. The present status for district wise installed watermills is as follows: Total no of watermills (15449 nos) are categorized into, traditional watermills (14882 nos) and upgraded watermills (499 nos)



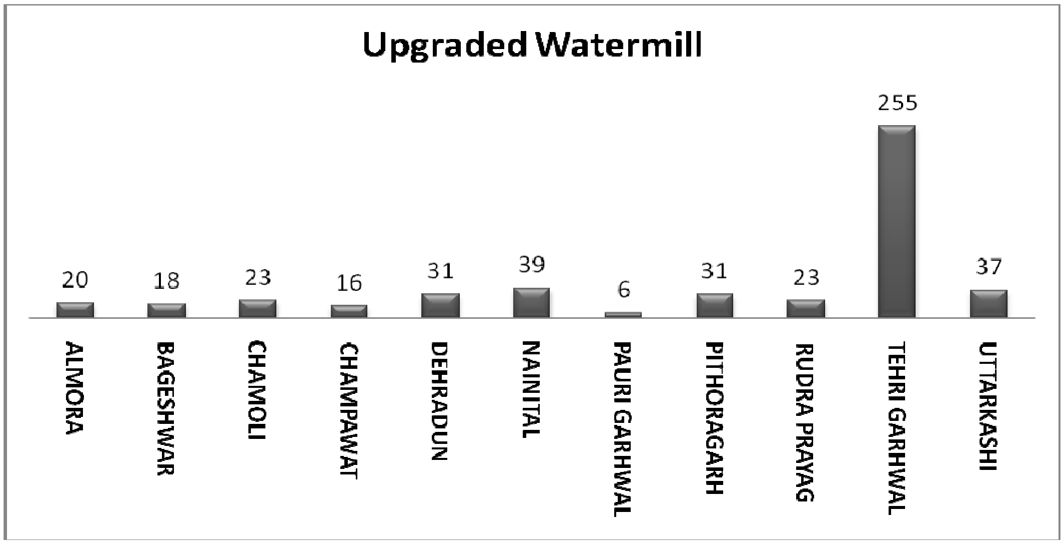
(Districtwise Population of TraditionalWatermill)



(Overall status of Updraded and Traditional Watermill)

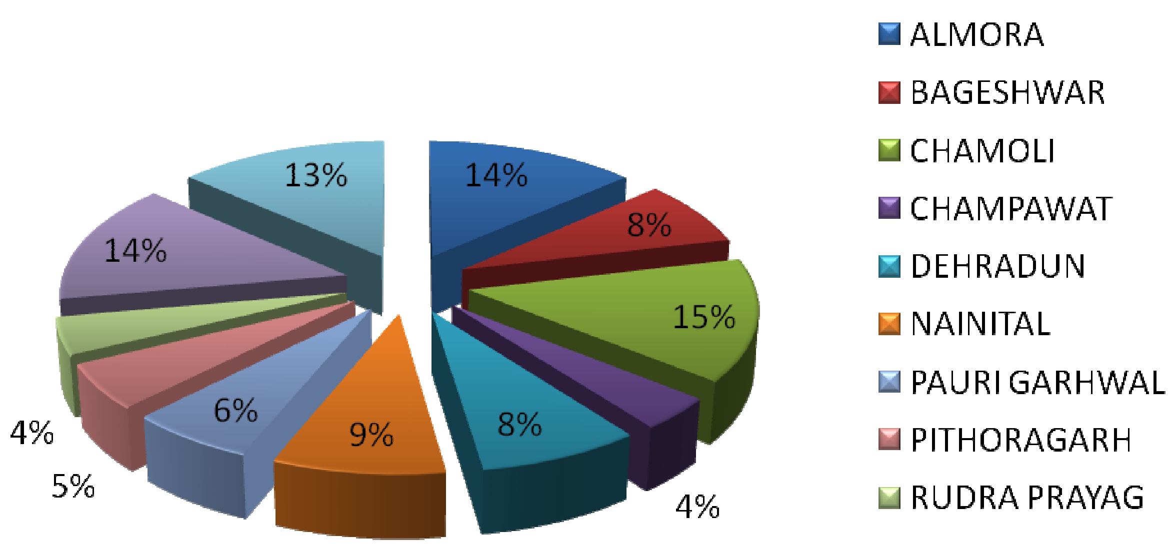
b. Upgraded Watermill

The turbine is simply an upgraded local design. The new system replaced the wooden water wheel with a cast steel runner mounted on a steel shaft. The flat wooden fins of the water wheel have been curved to harness maximum energy.

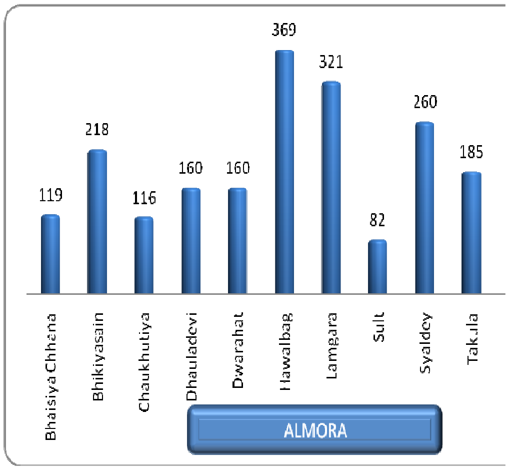


(Districtwise Population of Upgraded Watermill)

c. District wise Status of Existing Watermills



(Overall Status of Watermills in Uttaranchal)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160
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Bhikiyasain
Chaukhutiya
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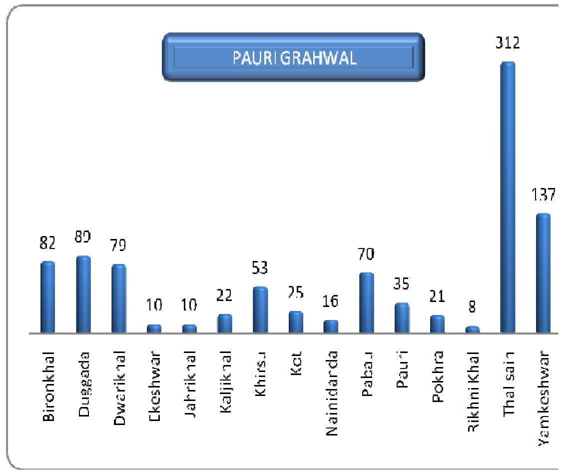
Dwarahat
Lamgara
Salt
Syaldey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Kaljikhal
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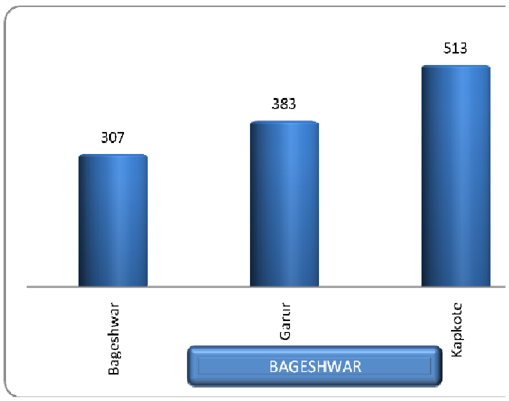
Nainidanda
Pokhra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Bageshwar
Garur
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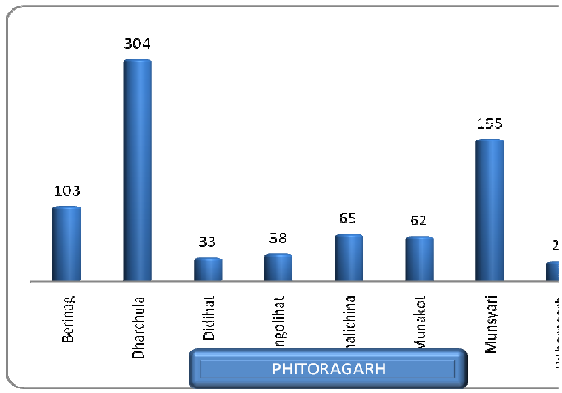
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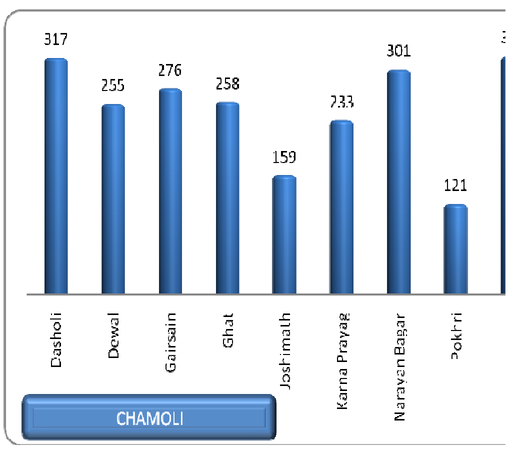
Didihat
Munsyari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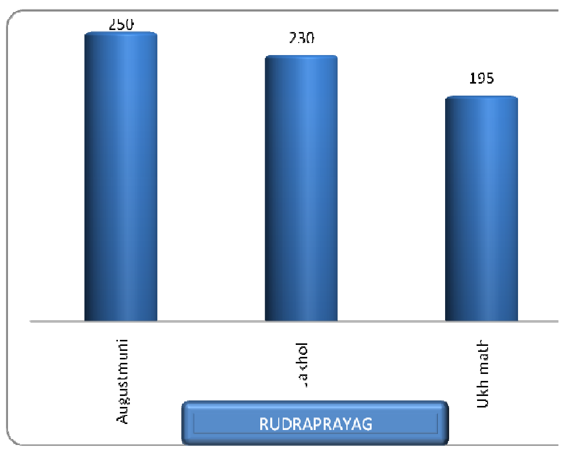
Dasholi
Dewal
Gairsain
Ghat
Karna Prayag
Narayan Bagar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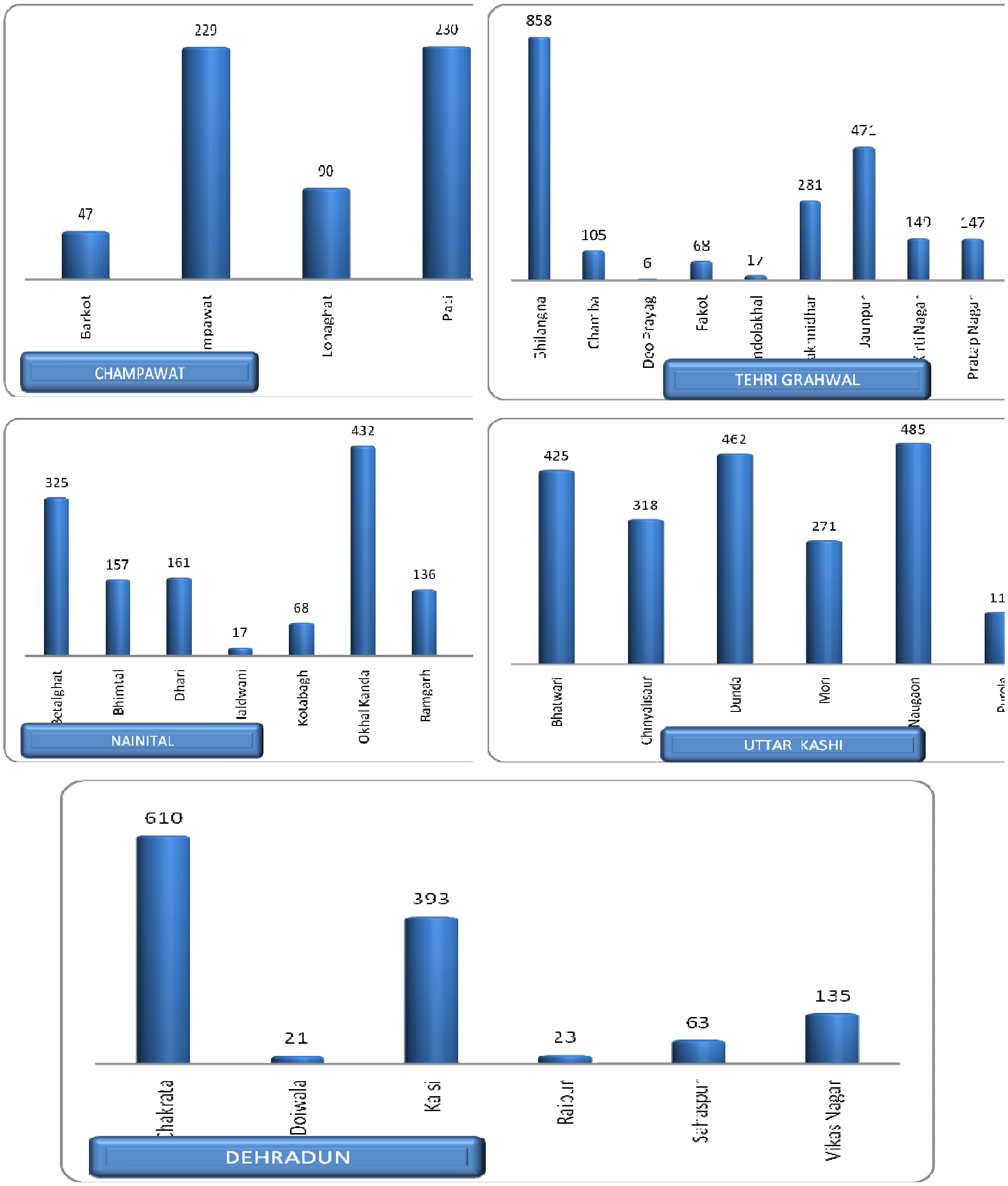
230
195
Augustmuni
Ukh math

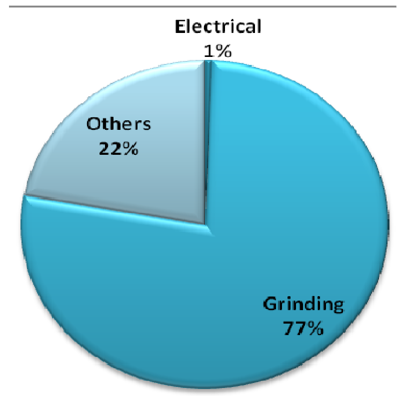


(District wise Status of Watermills in Uttaranchal)

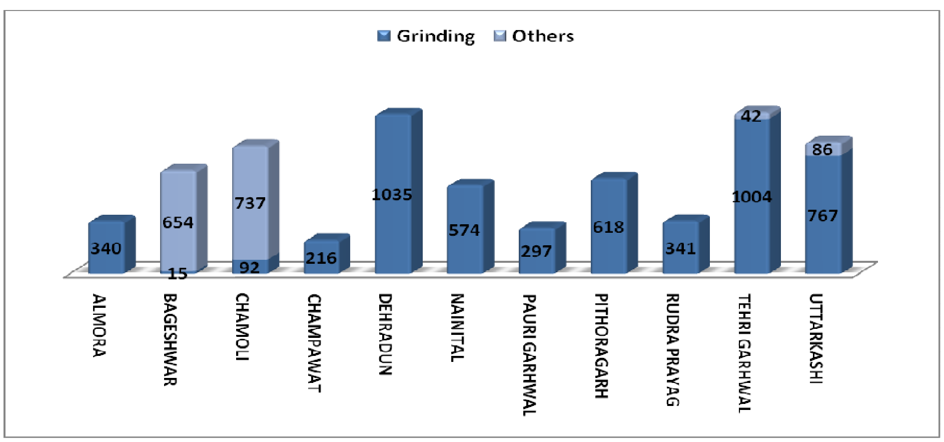
3.4.2 Current usage of Watermills

Presently, More than 95% of them are used for mechanical purpose, i.e. grinding of grains. The use of gharat for mechanical purpose can be one of the earning methods.

(**Fig 3.1:** Woman Grinding Grains at a Watermill in Chakrata dated 18.06.2008)



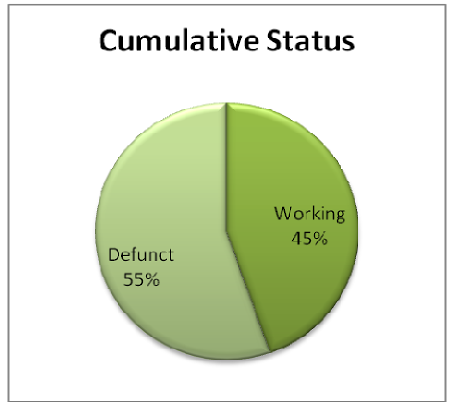
(Current Usage of Watermills)



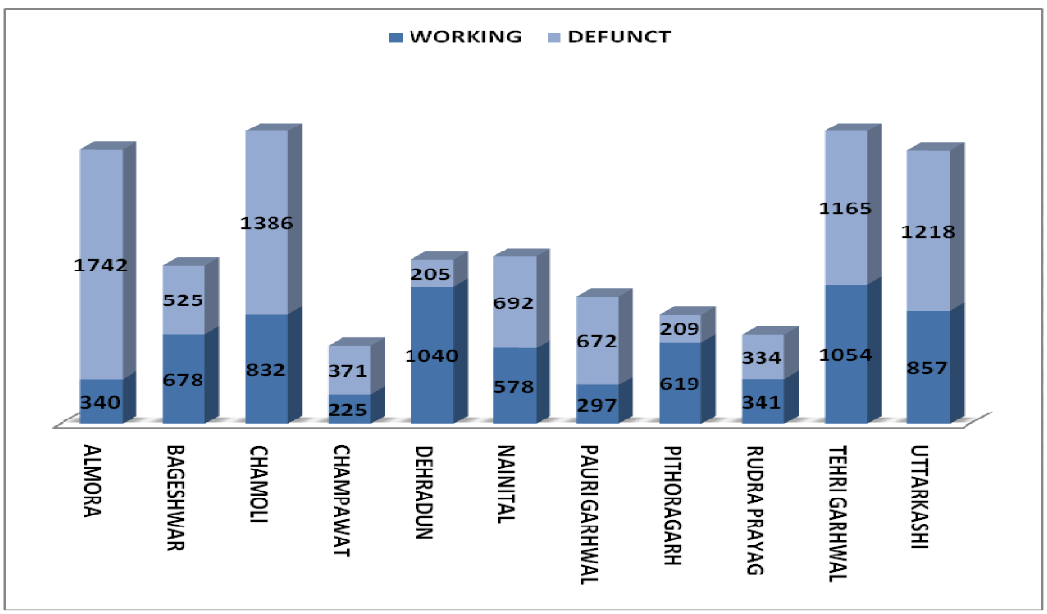
(Districtwise Usage Pattern of Watermills)

3.4.3 Working condition of watermills

The working condition of watermill differentiates between the working and non working watermills. Some watermills are not functioning due the maintenance problems. From the cumulative status of watermills, about 55% of them are defunct.



(Working condition of watermills)

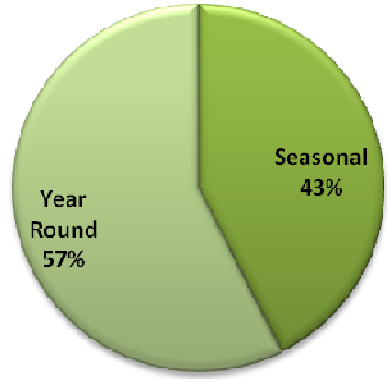


(Districtwise working condition of watermills)

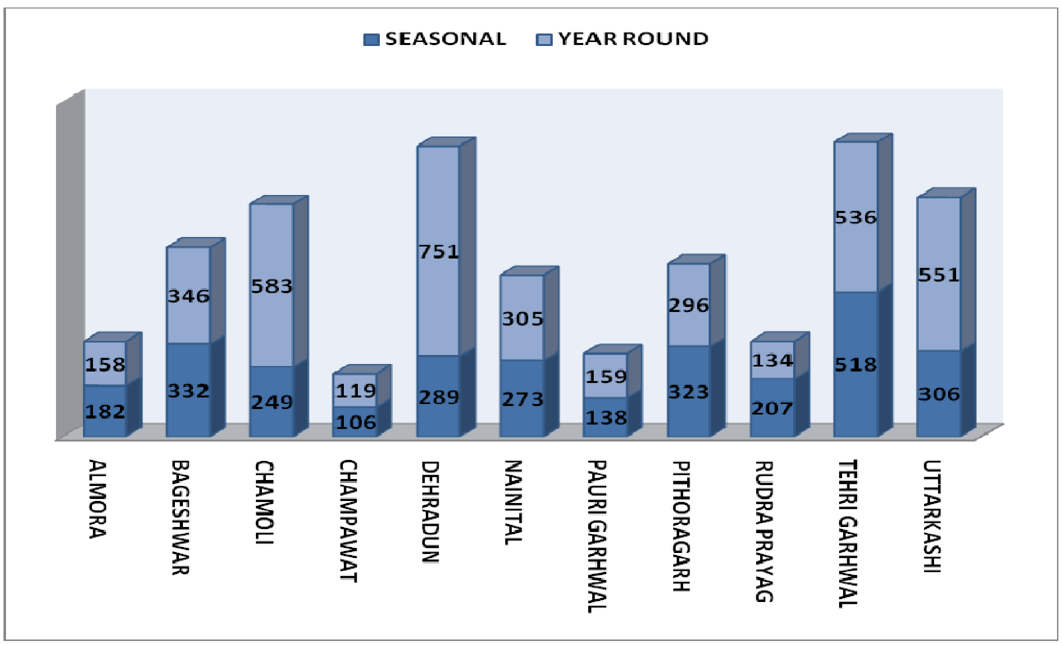
3.4.4 Majority of watermills work year round.

No of watermills working seasonally – 3672

No of watermills working year round - 4294



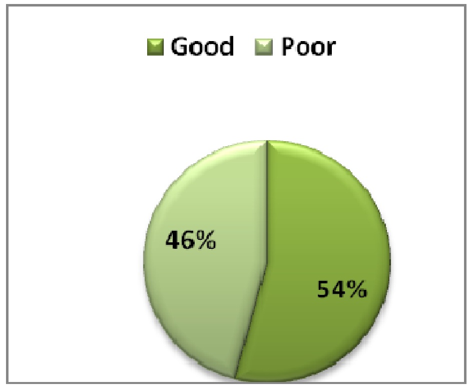
(Working Duration of Watermills)



(Distrctwise Working condition of watermill)

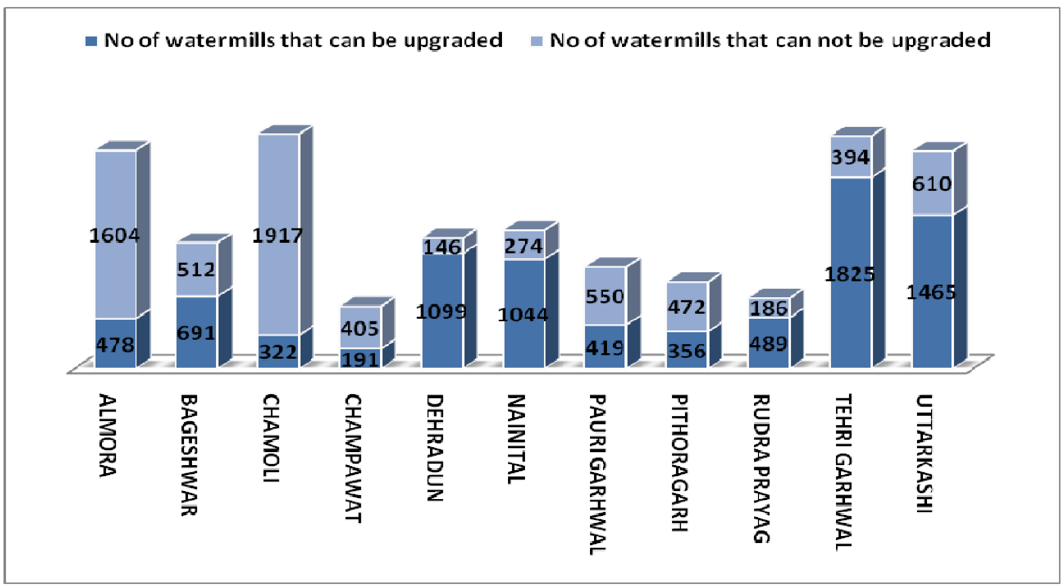
3.4.5 Potential for Up Gradation of Watermills

There exist a lot of potential for up gradation of Gharats. Total 8379 nos. can be upgraded (54% of total Base).



(Potential for Up Gradation of Watermills)

Remaining defunct watermills have low potential for upgradation due to damaged site condition, economic and poor hydrological constraints.



(Districtwise Potential for Up Gradation of Watermills)

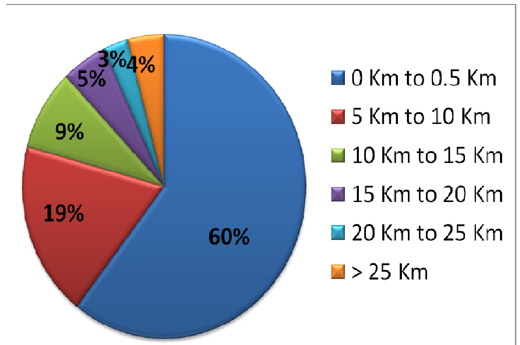
3.4.6 Watermills are located at a great distance from village

60% watermills are at < 5 kms

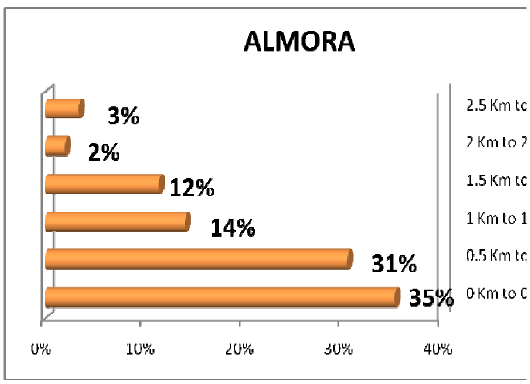
18% watermills are between 5 – 10 kms

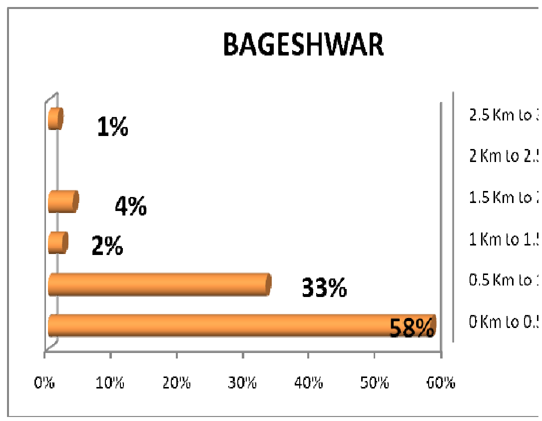
14% watermills are between 10 – 20 kms

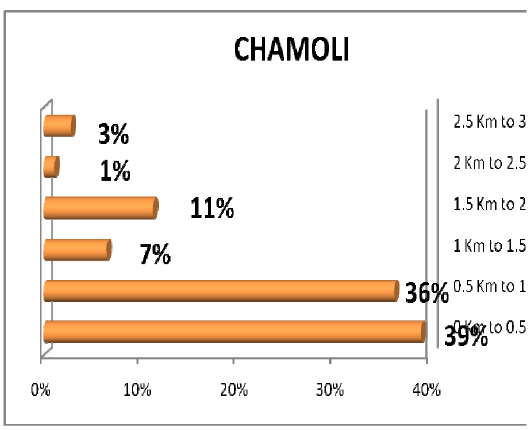
7 % watermills are at > 29 km distance.

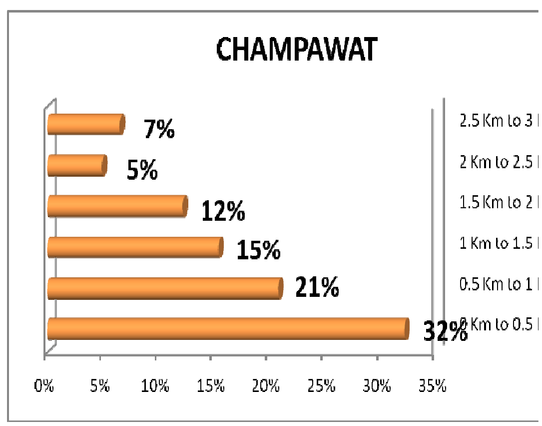


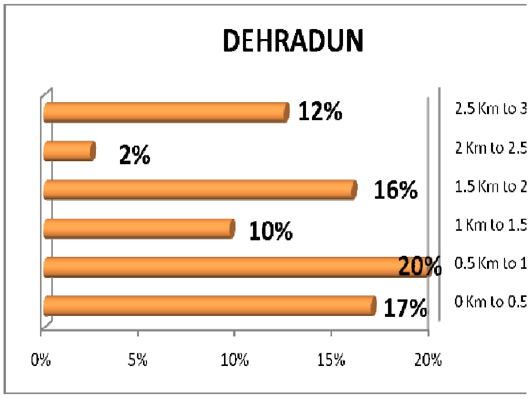
(Distance of Watermills from Village)

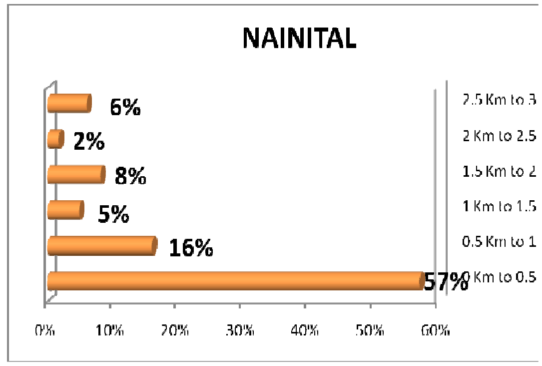









DEHRADUN
12%
2%
16%
10%
20%
17%
2.5 Km to 3
2 Km to 2.5
1.5 Km to 2
1 Km to 1.5
0.5 Km to 1
0 Km to 0.5
0%
5%
10%
15%
20%


NAINITAL
6%
2%
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16%
57%
2.5 Km to 3
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1.5 Km to 2
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0 Km to 0.5
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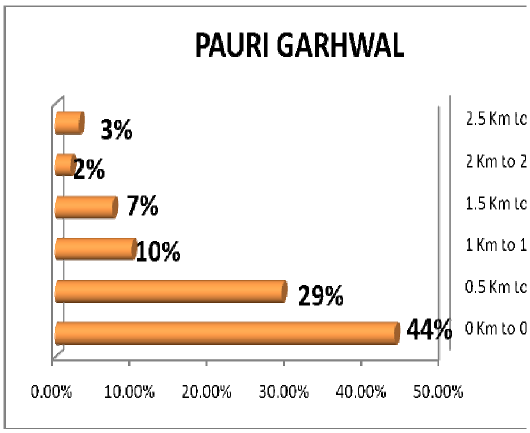
10%
20%
30%
40%
50%
60%


PAURI GARHWAL
3%
2%
7%
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29%
44%
2.5 Km to
2 Km to 2
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0 Km to 0
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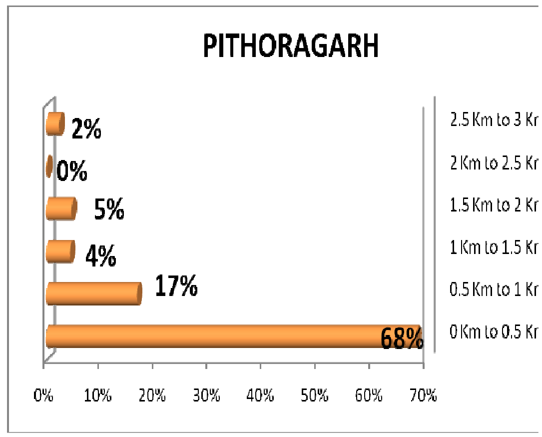
10.00%
20.00%
30.00%
40.00%
50.00%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0%
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1 Km to 1.5 Kr
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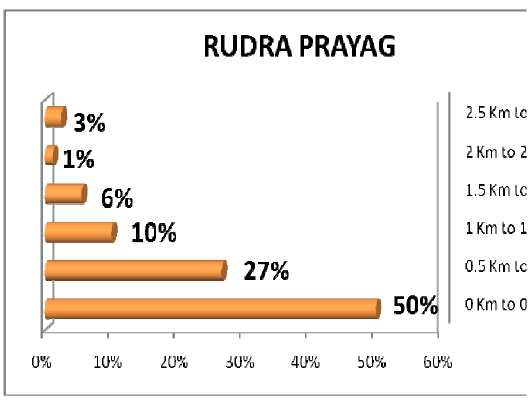
20%
30%
40%
50%
60%
70%


RUDRA PRAYAG
3%
1%
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2.5 Km to
2 Km to 2
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0 Km to 0
0%
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30%
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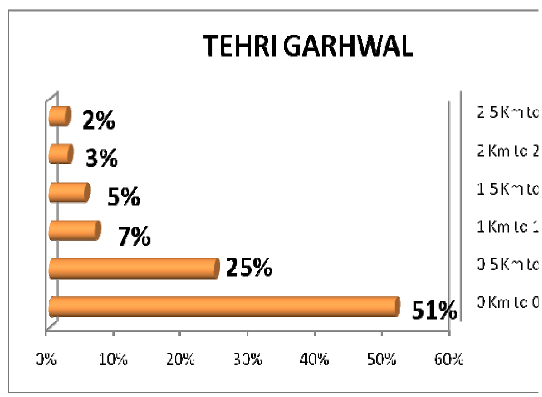
60%


TEHRI GARHWAL
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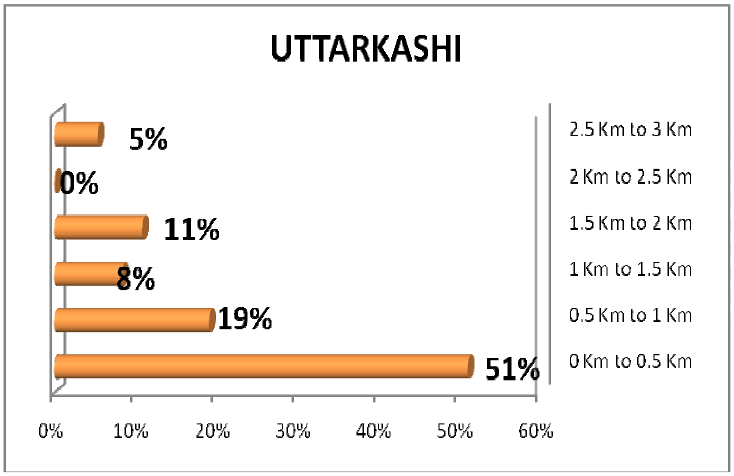
3%
5%
7%
25%
51%
0%
10%
20%
30%
40%
50%
60%



(Districtwise Status for 'Distance of Watermills from Village')

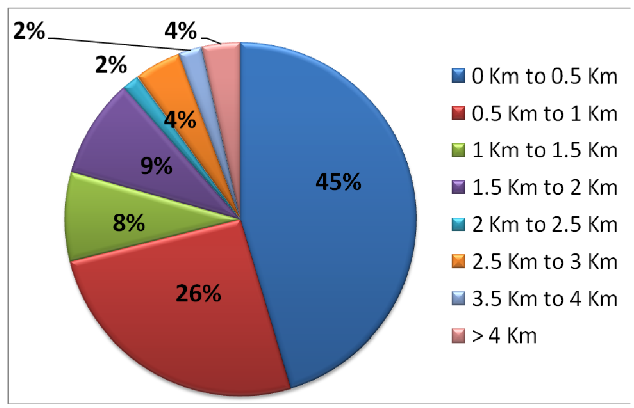
3.4.7 Watermills are Located at a Great Distance from Road Head

83% water mills are at < 5 kms,

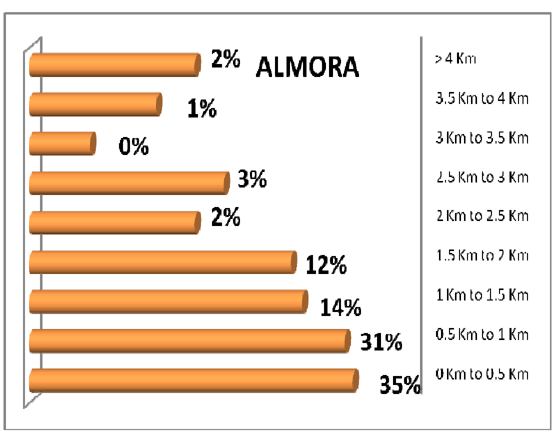
11.7% watermills are at 5 – 10 kms

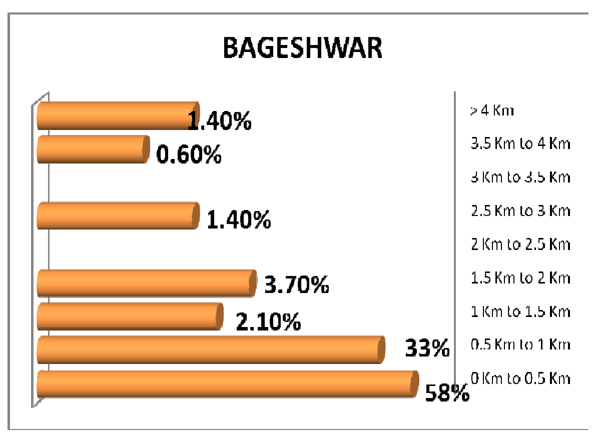
Remaining are even

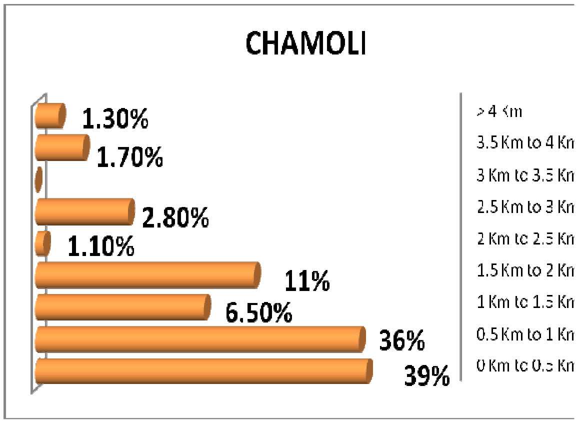
beyond 10 kms from road head.

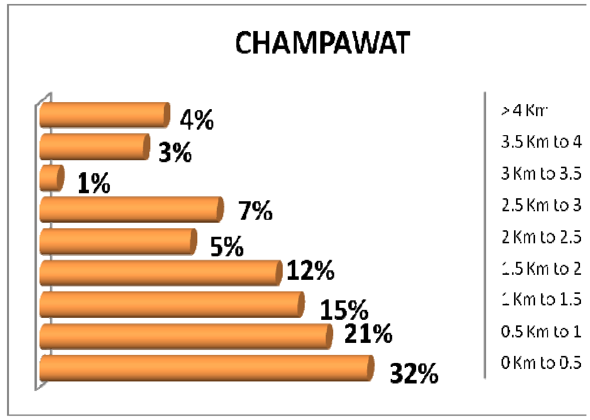


(Distance of Watermills from Road Head)






CHAMOLI
1.30%
1.70%
2.80%
1.10%
11%
6.50%
36%
39%
> 4 Km
3.5 Km to 4 Km
3 Km to 3.5 Km
2.5 Km to 3 Km
2 Km to 2.5 Km
1.5 Km to 2 Km
1 Km to 1.5 Km
0.5 Km to 1 Km


CHAMPAWAT
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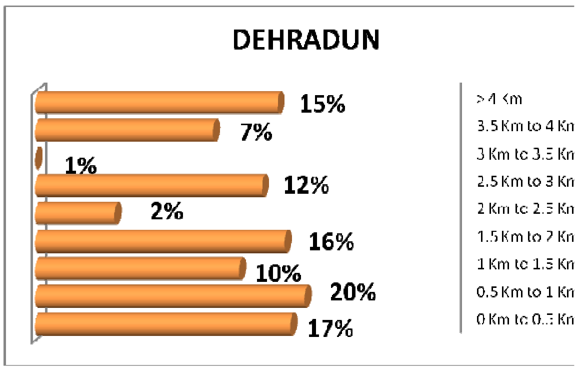
3%
1%
7%
5%
12%
15%
21%
32%
3.5 Km to 4
2.5 Km to 3
2 Km to 2.5
0.5 Km to 1
0 Km to 0.5


DEHRADUN
15%
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16%
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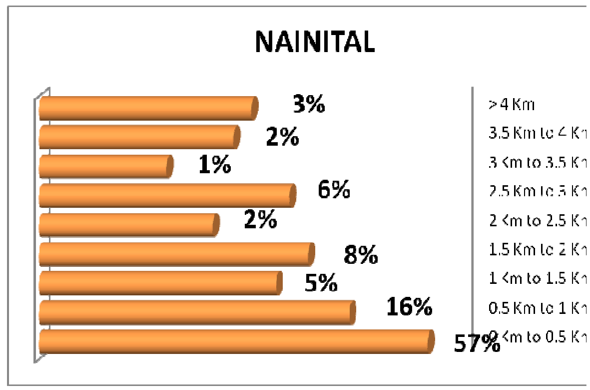
17%
3.5 Km to 4 Km
3 Km to 3.5 Km
2.5 Km to 3 Km
1 Km to 1.5 Km
0.5 Km to 1 Km


NAINITAL
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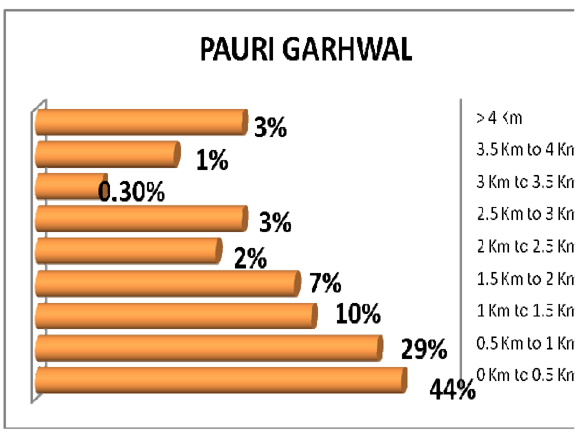
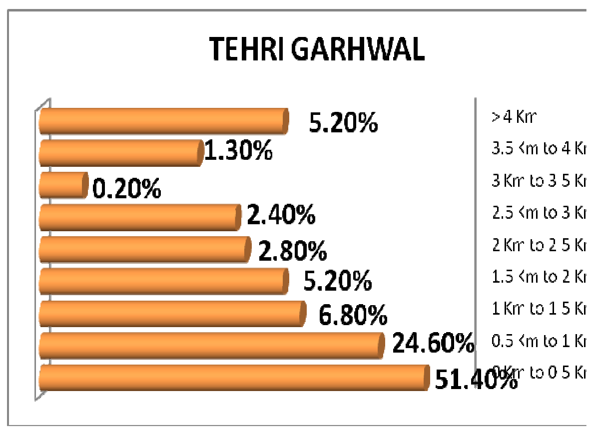
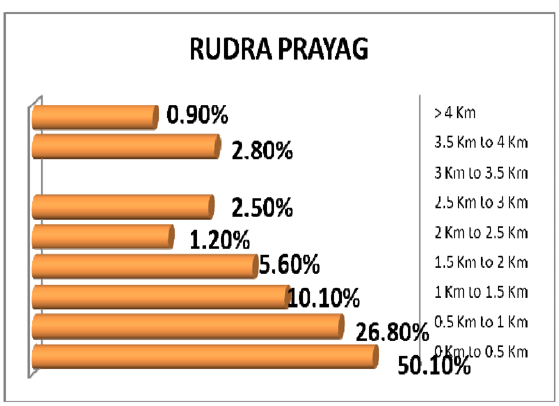
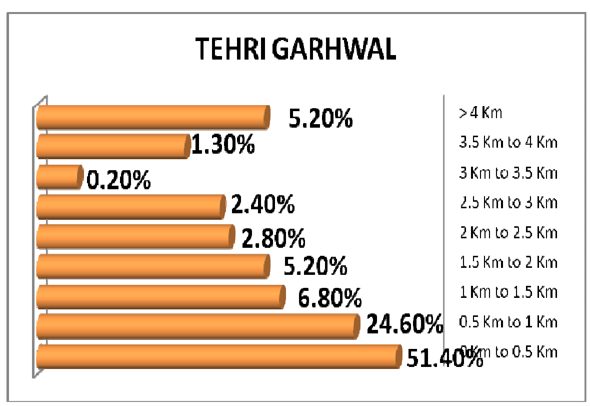
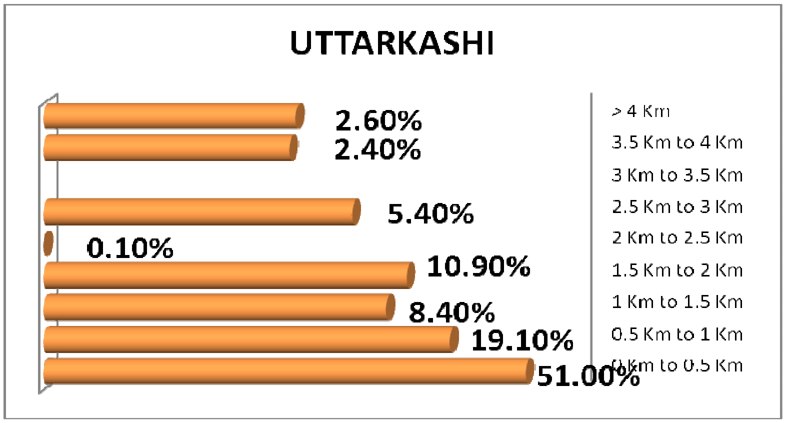
2%
8%
5%
16%
57%
> 4 Km


PAURI GARHWAL
3%
1%
0.30%
3%
2%
7%
10%
29%
44%
3.5 Km to 4 Km
3 Km to 3.5 Km
2.5 Km to 3 Km
2 Km to 2.5 Km
1.5 Km to 2 Km
1 Km to 1.5 Km
0.5 Km to 1 Km
0 Km to 0.5 Km


TEHRI GARHWAL
5.20%
1.30%
0.20%
2.40%
2.80%
5.20%
6.80%
24.60%
51.40%

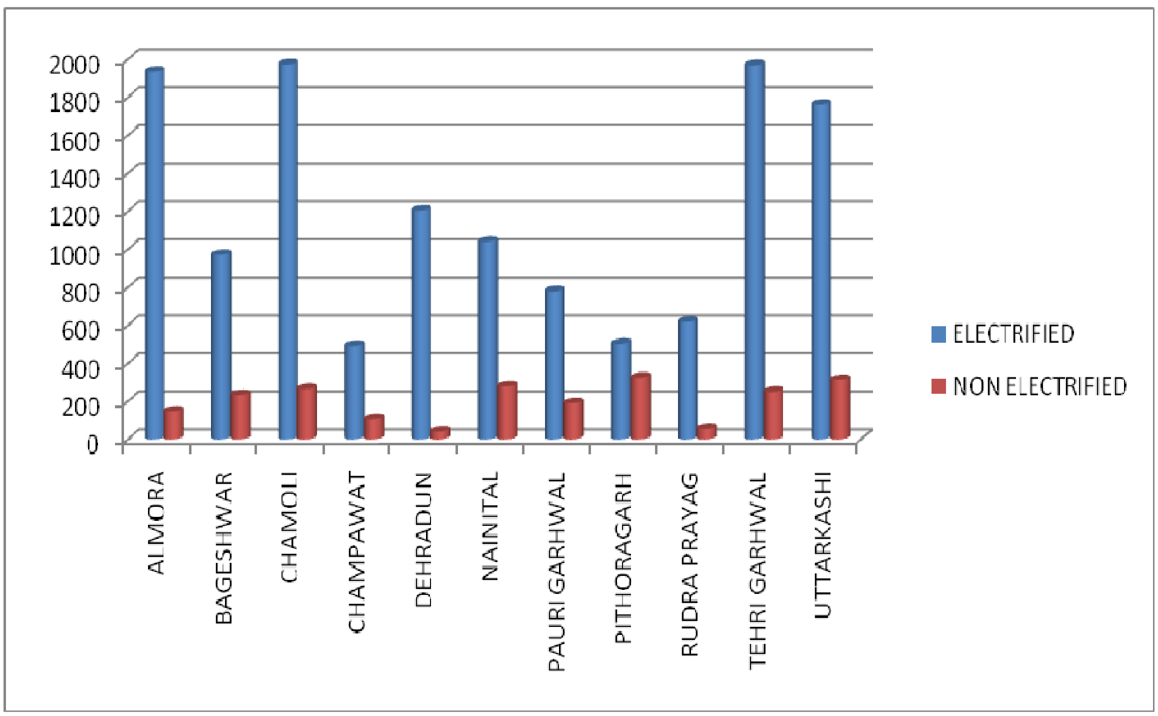

RUDRA PRAYAG
0.90%
2.80%
2.50%
1.20%
5.60%
10.10%
26.80%
50.10%
> 4 Km
3.5 Km to 4 Km
3 Km to 3.5 Km
2.5 Km to 3 Km
2 Km to 2.5 Km
1.5 Km to 2 Km
1 Km to 1.5 Km
0.5 Km to 1 Km
0 Km to 0.5 Km


TEHRI GARHWAL
5.20%
1.30%
0.20%
2.40%
2.80%
5.20%
6.80%
24.60%
51.40%
> 4 Km
3.5 Km to 4 Km
3 Km to 3.5 Km
2.5 Km to 3 Km
2 Km to 2.5 Km
1.5 Km to 2 Km
1 Km to 1.5 Km
0.5 Km to 1 Km
0 Km to 0.5 Km

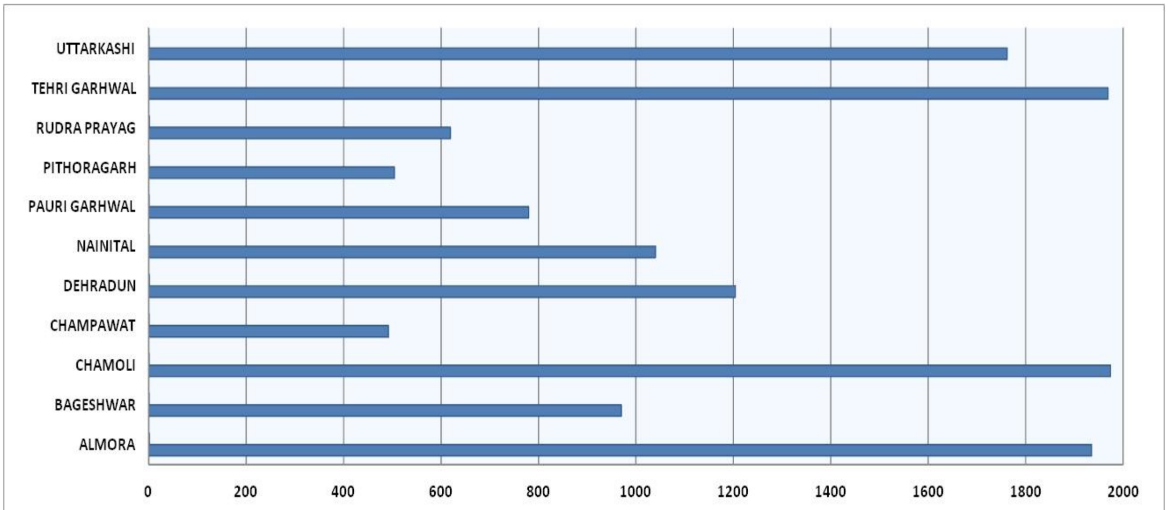


(Districtwise Status for 'Distance of Watermills from Road Head')

3.4.8 Status of Electrification



(Districtwise Status of Village Electrification in Uttaranchal)

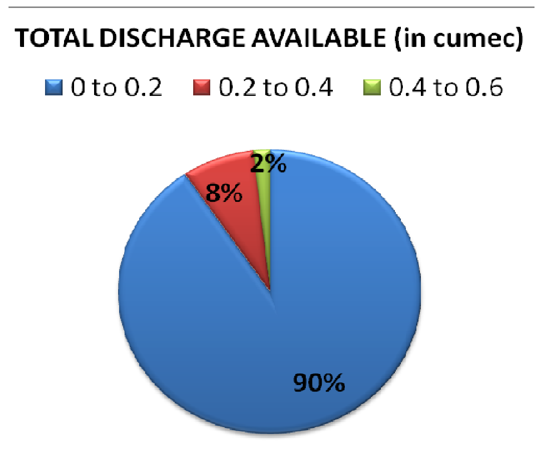


	ALMORA	BAGESHWAR	CHAMOLI	CHAMPAWAT	DEHRADUN	NAINITAL	PAURI GARHWAL	PITHORAGARH	RUDRA PRAYAG	TEHRI GARHWAL	UTTARKASHI
percentage	92.90%	80.60%	88.20%	82.60%	96.70%	78.90%	80.50%	60.90%	91.70%	88.70%	84.90%
Nos	1935	970	1974	492	1204	1040	780	504	619	1969	1762

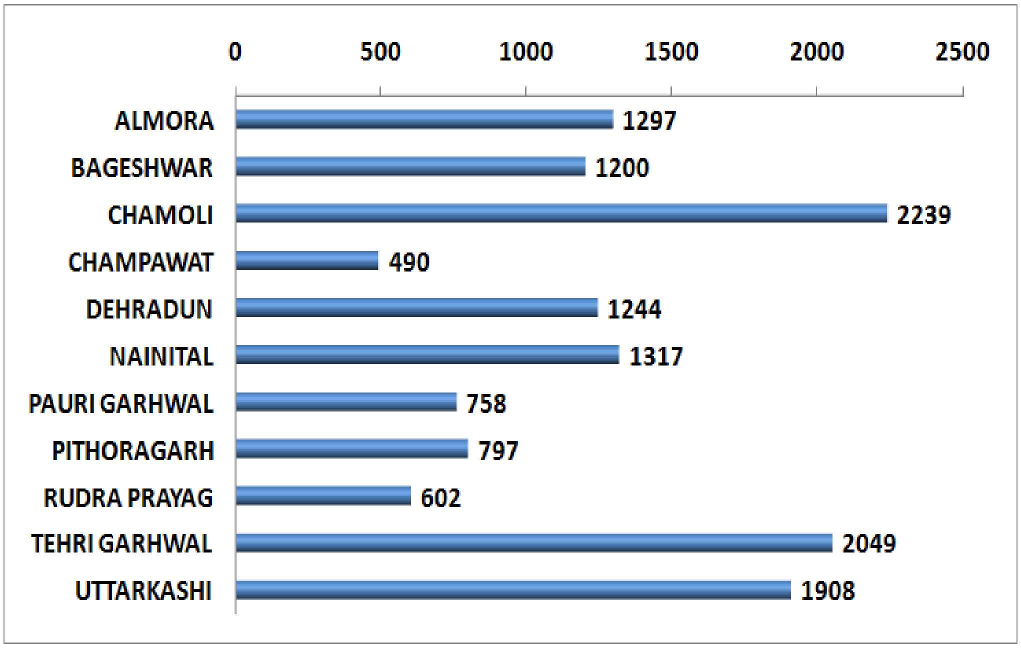
(Districtwise Status of Electrification in Uttaranchal)

3.4.9 Average Annual Discharge

At about 98% locations average annual discharge is 0 – 0.2 cumec.

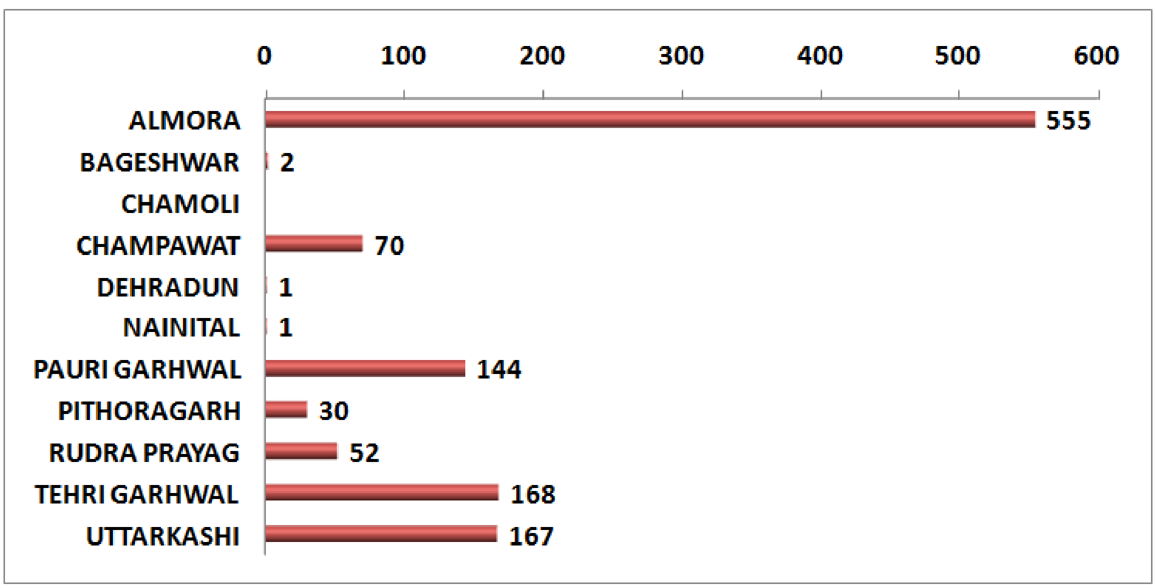


(Cumulative Average Annual Discharge)



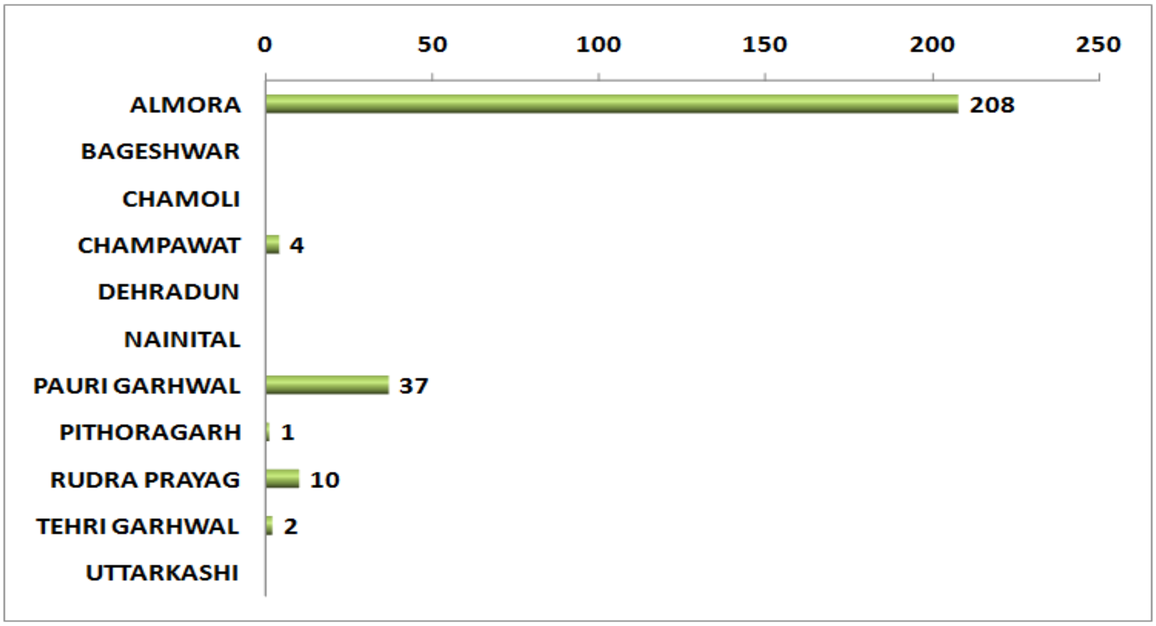
(Average Annual Discharge from 0 to 0.2 Cumec)

The Chamoli, Tehri garhwal and Uttarkashi has 99% locations of average annual discharge is 0 to 0.2 Cumec.



(Average Annual Discharge from 0.2 to 0.4 Cumec)

The Almora district has 27% of locations having average annual discharge of 0.2 to 0.4 Cumec.

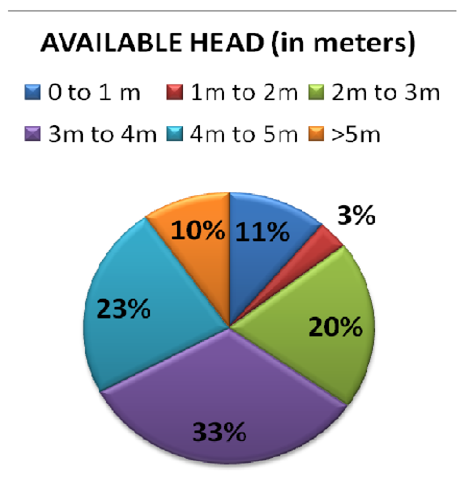


(Average Annual Discharge from 0.4 to 0.6 Cumec)

The Almora district has 10% of locations having average annual discharge of 0.4 to 0.6 Cumec.

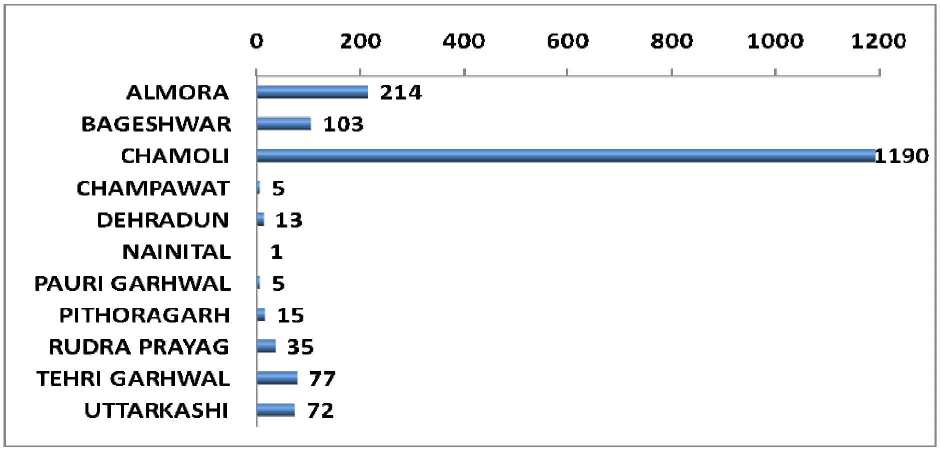
3.4.10 Available Head

At about 75% locations head varies from 2 – 5 meters.

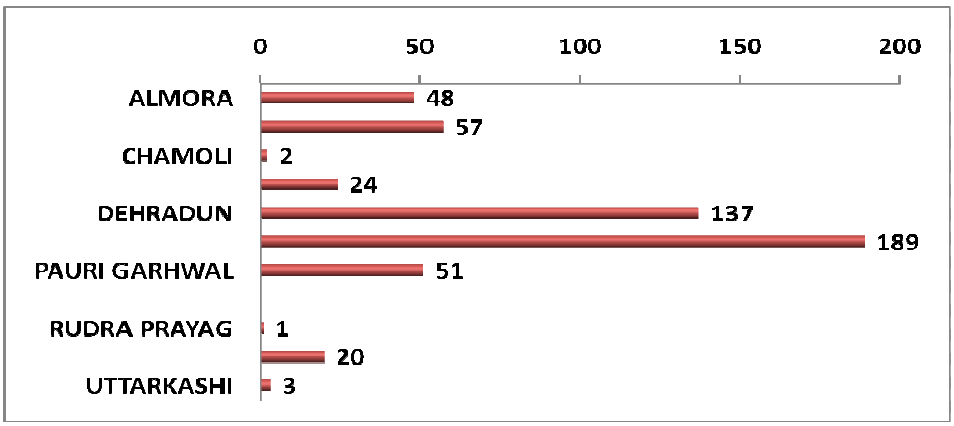


(Cumulative Status of Available Head)

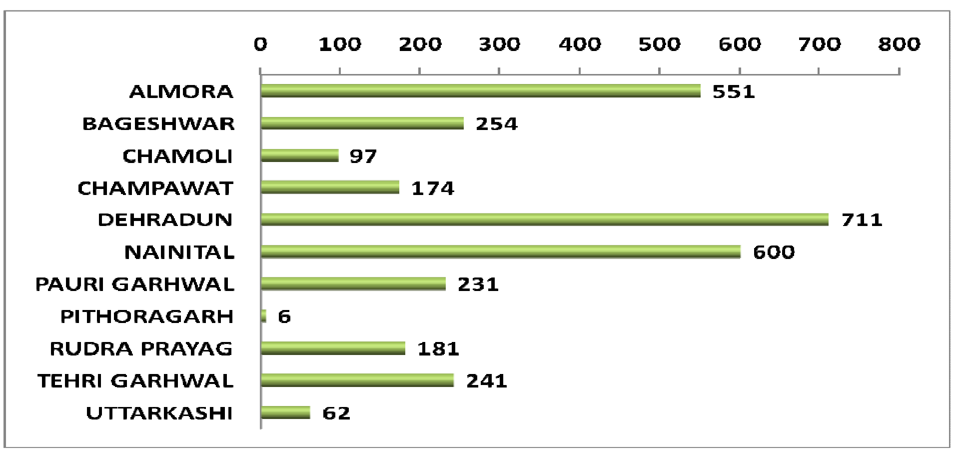
Head (0 -1m)



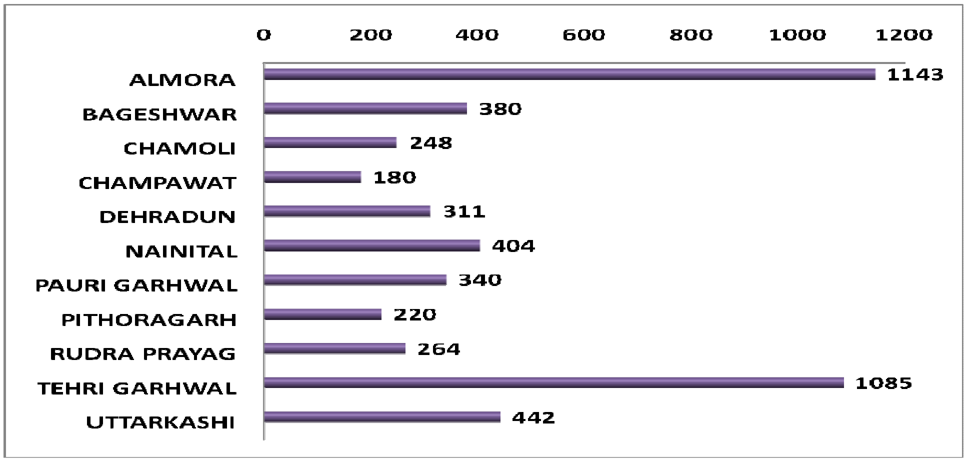
Head (1 -2m)



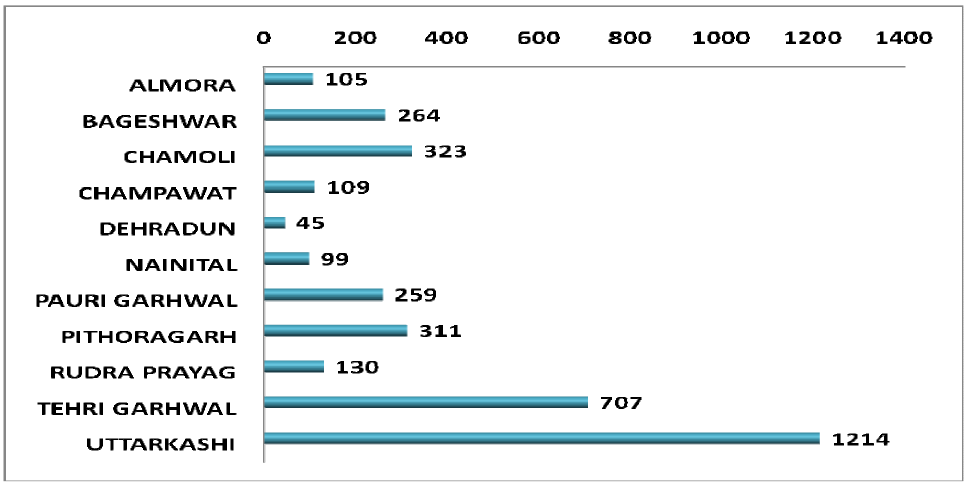
Head (2 -3m)



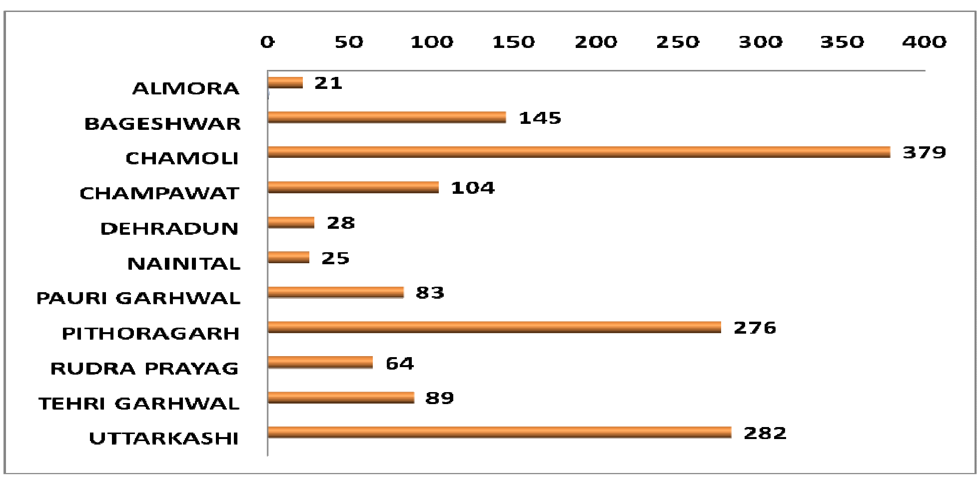
Head (3 -4m)



Head (4 -5m)

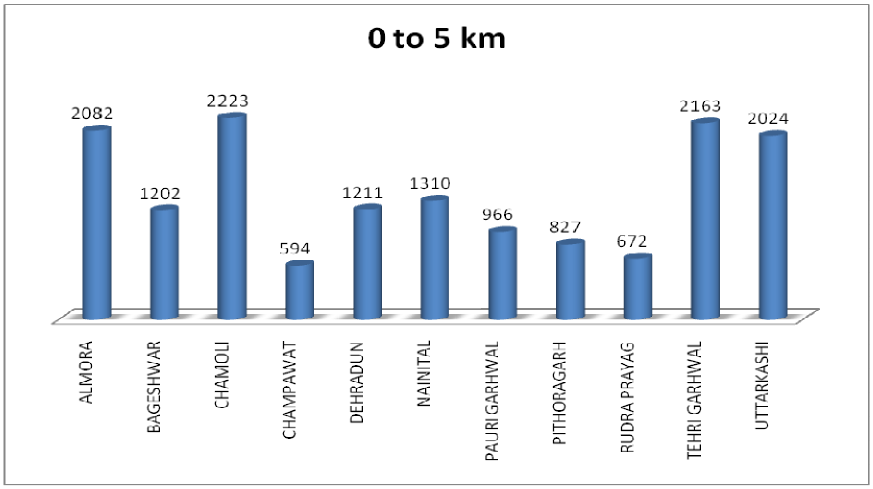


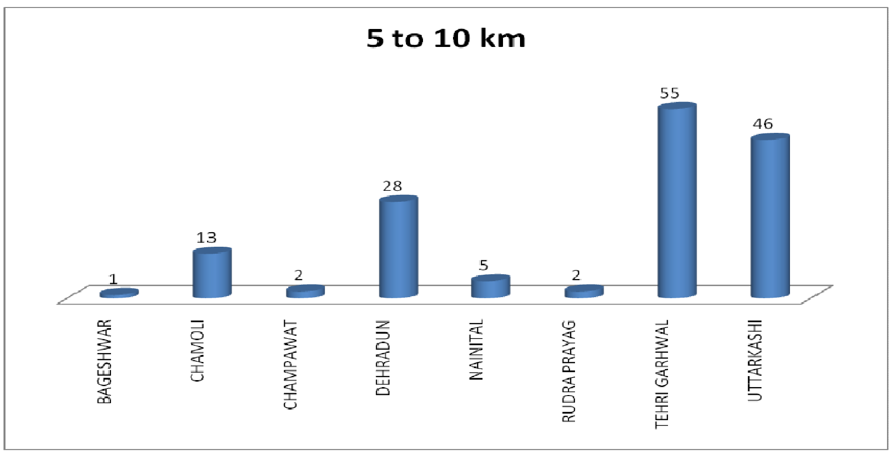
Head (>5m)



(Districtwise Status of Available Head)

3.4.11 Distance of Water Mills from Nearest Village

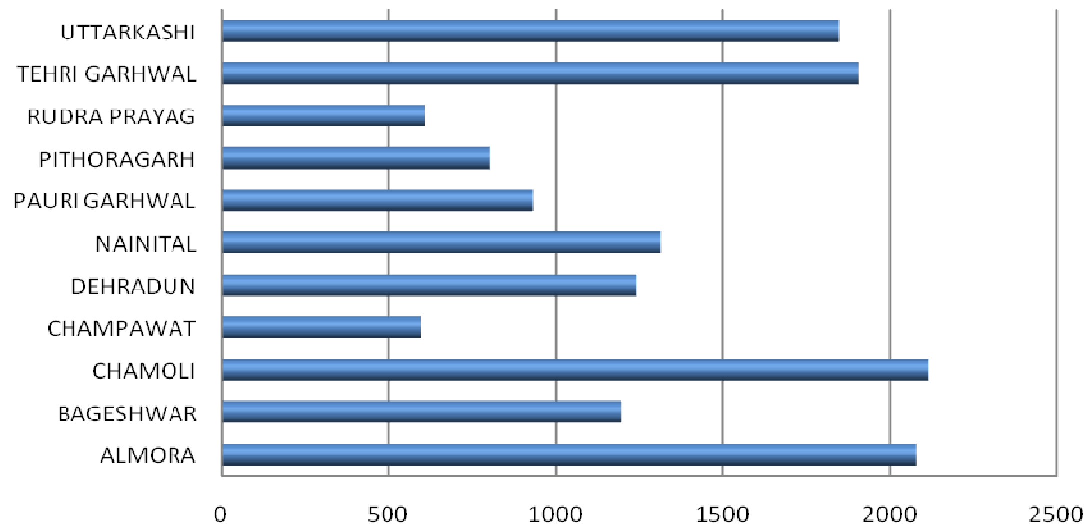




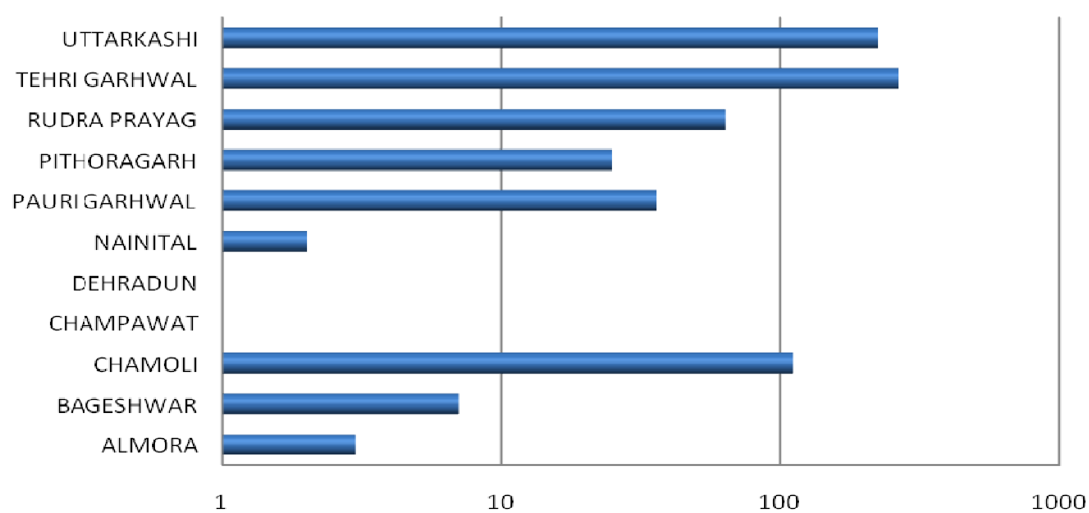
(Districtwise Status for 'Distance of Water Mills from Nearest Village')

3.4.12 No of Households Within 500 m

(0-200m)



	ALMORA	BAGESHWAR	CHAMOLI	CHAMPAWAT	DEHRADUN	NAINITAL	PAURI GARHWAL	PITHORAGARH	RUDRA PRAYAG	TEHRI GARHWAL	UTTARKASHI
0 to 200 m	2077	1196	2117	596	1241	1313	931	800	607	1906	1849

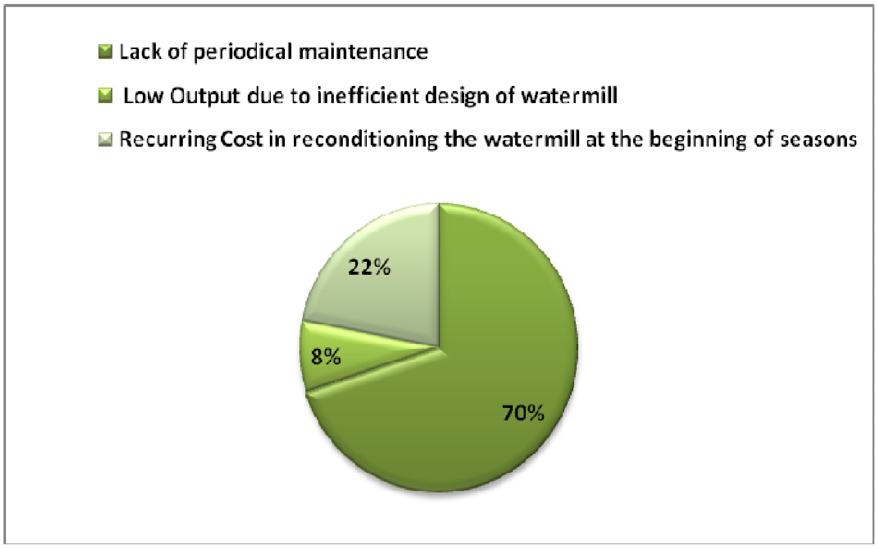


	ALMORA	BAGESHWAR	CHAMOLI	CHAMPAWAT	DEHRADUN	NAINITAL	PAURI GARHWAL	PITHORAGARH	RUDRA PRAYAG	TEHRI GARHWAL	UTTARKASHI
200 - 400 m	3	7	111		1	2	36	25	64	266	225

(Districtwise Status for 'No of Households Within 500 m)

3.4.13 Reasons for Non Functioning of Watermill

Even the existing upgraded watermill owners are unhappy due to maintenance problems; very few are interested in upgrading the watermill.



(Cumulative Status of Reasons for Non Functioning of Watermill)

The survey indicates that, there are three main reasons for non functioning

I. Lack of periodical maintenance
II. Low Output due to inefficient design of watermill
III. Recurring Cost in reconditioning the watermill at the beginning of seasons.

3.5 OTHER OBSERVATIONS

- Majority of watermills are defunct due to maintenance problems.
- The distance of watermill from village and the road head make the owner disinterested in operating and maintaining the watermill.

(**Fig 3.2:** Photograph of a watermill taken just below the road head at Pipalkoti, Chamoli dated 22.06.2008)

- Heavy weight of wooden turbine causes low RPM and hence low output per hour.
- Mis-match by fabricating heavy turbine vis-a-vis available hydro power potential (head, flow etc)

Fig 3.3: Traditional runner of a watermill at Ukhimath dated 23.06.2008)

- Wooden runner and blades get damaged quite frequently. Blades come out of runner.

(**Fig 3.4:**Miller showing his damaged runner of a watermill at Ukhimath dated 23.06.2008)

- Use of open channel made up of stones as penstock causing loss of head due to friction, spillage of water.
- Unavailability of screen at entrance of channel causing trash and boulders to be carried up to turbine.
- Deposition of elegy and growth of plants in channel causes loss of head.

(**Fig 3.5:**Open penstock of a watermill at Chakrata dated 18.06.2008)

- Improper angle of penstock nozzle, causing imperfect strike of water on turbine blade. Damaged penstock nozzle causing water to spill all over.

(**Fig 3.6:**Damaged Penstock Nozzle at a Watermill at Bhatwari dated 20.06.2008)

- There is no provision of controlling the water.

  During rainy seasons the water become violent and carries lots of sediment & boulders with it. These boulders and sediment effect the turbines hence the watermill has to be closed during the seasons of high discharge.

(**Fig 3.7:**Damaged watermill turbine at Tehri dated 16.06.2008)

- There was breaching of the open channel just before the fore bay tank which reduced the discharge.

(**Fig3.8:**Breached Channel at a site in Bhimtal dated 28.06.2008)

- The channel is situated just downhill the road, so the slope lead to the direct dropping of leaves and other waste materials in the channel.
- This garbage material was blocking the way of penstock

(**Fig3.9:**Trash accumulation at a site in Almora dated 29.06.2008)

- The screening of materials has the temporary adjustments with wooden trap which was not efficient.

(**Fig3.10:**Wooden Screen at a site in Almora dated 29.06.2008)

- Flour dripping in bearing causes its frequent failure/ jamming
- Lots of flour gets wasted as it flies all over the places during grinding.

3.6 LAB TESTING OF EXISTING IMRPOVED WATERMILLS

Firstly improved watermill is compared with conventional watermill and to determine the efficiency, the improved runner having 500 mm runner diameter was tested in laboratory. The test results are given in Table below.

Sr. No.	Head H (m)	Discharge Q (m^3/sec)	Input Power Pi= 9.8xQx H (kW)	Dynamometer Reading		Torque T=(T1-T2) x r (Nm)	Speed N (rpm)	Output Power Po=NT/ 9550 (kW)	Efficiency ή=(Po/Pt) x 100
				Tension at tight side T1 (N)	Tension at slack sideT1 (N)				
1.	3.3	0.03985	1.2887	0	0	0	270	0	0
2.				58.8	0	4.259	260	0.116	8.999
3.				156.8	0	11.359	240	0.285	22.150
4.				235.6	9.8	16.357	220	0.377	29.239
1.	3	0.03768	1.1077	0	0	0	260	0	0
2.				58.8	0	4.259	250	0.112	10.066
3.				176.4	9.8	12.069	220	0.278	25.099
4.				294	19.6	19.878	200	0.416	37.581
1.	2.6	0.03473	0.8849	0	0	0	210	0	0
2.				190	9.0	13.488	185	0.254	28.730
3.				297	19.5	19.878	178	0.375	42.339
4.				431.2	39.2	28.396	150	0.446	50.403

(**Table 3.1:** Result of Improved Water Mill)

However, in order to compare the efficiency of improved runner a traditional wooden runner has also been tested. The test results of wooden runner are given below.

S. No.	Head H (m)	Discharge Q (m^3/sec)	Input Power Pi= 9.8xQx H (kW)	Dynamometer Reading		Torque T=(T1-T2) x r (Nm)	Speed N (rpm)	Output Power Po=NT/ 9550 (kW)	Efficiency ή=(Po/Pt) x 100
				Tension at tight side T1 (N)	Tension at slack sideT1 (N)				
1.	3.45	0.039	1.3185	0	0	0	165	0	0
2.				98.0	9.8	4.498	160	0.075	5.716
3.				196.0	29.4	8.497	150	0.133	10.122
4.				294.0	49.0	12.495	145	0.190	14.389
5.				392.0	58.8	16.993	140	0.249	18.894

1.	**2.8**	**0.0357**	**0.9796**	**0**	**0**	**0**	**150**	**0**	**0**
2.				**98.0**	**9.8**	**4.498**	**135**	**0.064**	**6.491**
3.				**196.0**	**29.4**	**8.497**	**130**	**0.116**	**11.807**
4.				**294.0**	**49.0**	**12.495**	**125**	**0.164**	**16.695**
5.				**392.0**	**58.8**	**16.993**	**120**	**0.214**	**21.797**
1.	**3**	**0.035**	**1.029**	**0**	**0**	**0**	**160**	**0**	**0**
2.				**58.8**	**0**	**2.999**	**150**	**0.047**	**4.577**
3.				**117.6**	**9.8**	**5.498**	**145**	**0.083**	**8.112**
4.				**215.6**	**29.4**	**9.496**	**135**	**0.134**	**13.046**

(**Table 3.2:** Result of Traditional Water Mill)

An attempt is made to compare the performance of these runners. Table above shows the variation in efficiency with respect to the speed of runner under different head for traditional water mill runner and improved water mill. Trend shows that the efficiency increases with decrease in speed. This is obvious that these turbines are high head turbines. From the above table, it is observed that the efficiency of the improved water mill runner has been improved by 2-4 times.

From above table, it is also observed that under a given head, traditional water mill operated at lower speed than the improved water mill runner. The reason could be explained on the line that the traditional water mill runner is having larger diameter than the improved water mill runner. A comparison in efficiency is made based on the test data which shows that efficiency of improved water mill has been improved substantially. It is observed from the results that the average efficiency obtained of the runners ranges from 8 to 17% for traditional runner and 22 to 43% for improved runner.

Presently available improved watermills can be categorized as per following types: Cross flow, Axial flow, Pelton, Improved watermills

To analyse their performance under different head and discharge, few samples of each type were collected from manufacturers and tested under lab condition.

3.7 TEST RESULTS

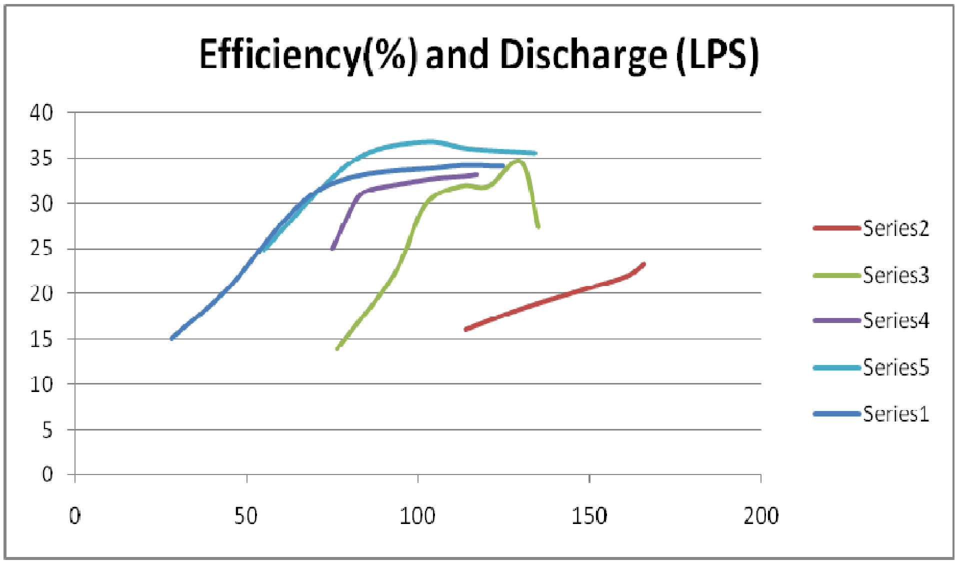
3.7.1 Crossflow turbine.

		TURBINE 1					TURBINE 2						
Dischage	LPS	113.74	129.99	147.99	160.42	165.7	76.1	92.9	101.8	112.3	120.3	129.9	134.9
Head	m	5.17	6.59	7.28	7.61	7.97	3.25	3.93	4.99	8.07	8.07	9.95	14.36
Output	kW	1.24	2.06	2.88	3.49	4.01	0.55	1.31	2.44	3.88	5	7.22	8.55
Input	kW	5.76	8.39	10.55	11.95	12.93	2.42	3.57	4.97	9.51	9.51	18.97	18.97
Loading	%	24.8	41.2	57.6	69.8	80.2	5.5	13.1	24.4	38.8	50	72.2	85.5
Efficiency	%	16.1	18.4	20.5	21.9	23.3	13.9	22.2	29.8	32.0	32.0	34.6	27.4

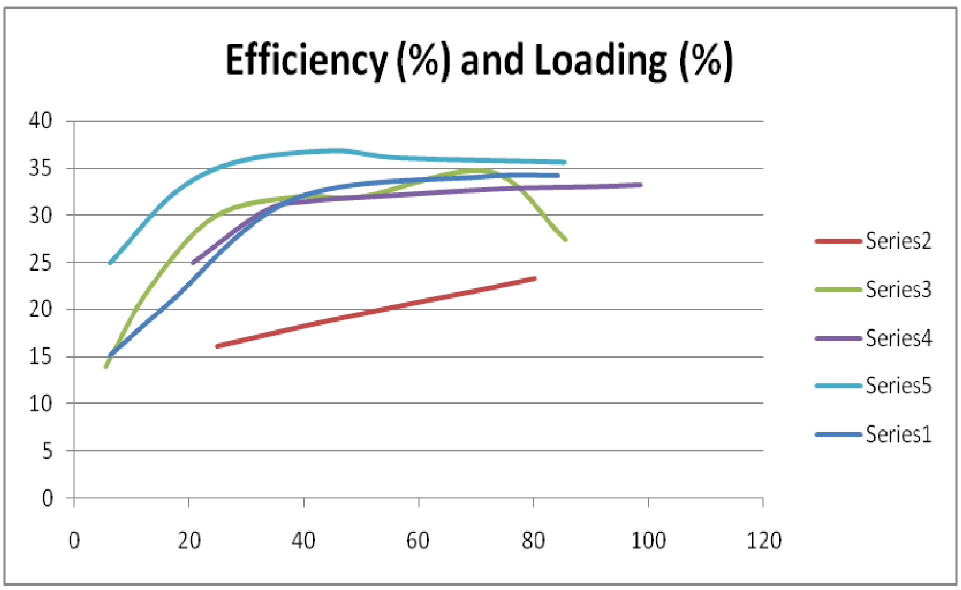
		TURBINE 3						
Dischage	LPS	75	82	86	95	105	113	117
Head	m	3.4	4.1	4.7	5.9	6.65	7.5	7.9
Output	kW	1.03	1.65	2.06	2.88	3.7	4.52	4.93
Input	kW	2.5	3.29	3.97	5.44	6.85	8.31	9
Loading	%	20.6	33	41.2	57.6	74	90.4	98.6
Efficiency	%	25.0	30.4	31.5	32.2	32.8	33.0	33.2

		TURBINE 4						TURBINE 5				
Dischage	LPS	55	73.5	86	102.7	114.7	133.9	28.2	44.3	71.7	107.3	124.7
Head	m	2.79	4.55	5.8	7.41	8.49	11.08	9	11.05	12	12.1	12.26
Output	kW	0.62	1.75	2.88	4.52	5.65	8.53	0.62	1.62	3.82	7.12	8.42
Input	kW	1.51	3.28	4.89	7.45	9.53	14.53	2.48	4.79	7.32	12.7	14.96
Loading	%	6.2	17.5	28.8	45.2	56.5	85.3	6.2	16.2	38.2	71.2	84.2
Efficiency	%	24.9	32.4	35.7	36.8	36.1	35.6	15.1	20.5	31.7	34.1	34.2

(**Table 3.3:** Test Result of Cross flow turbine)



('Efficiency V/s Discharge Curve' - Crossflow turbine testing)

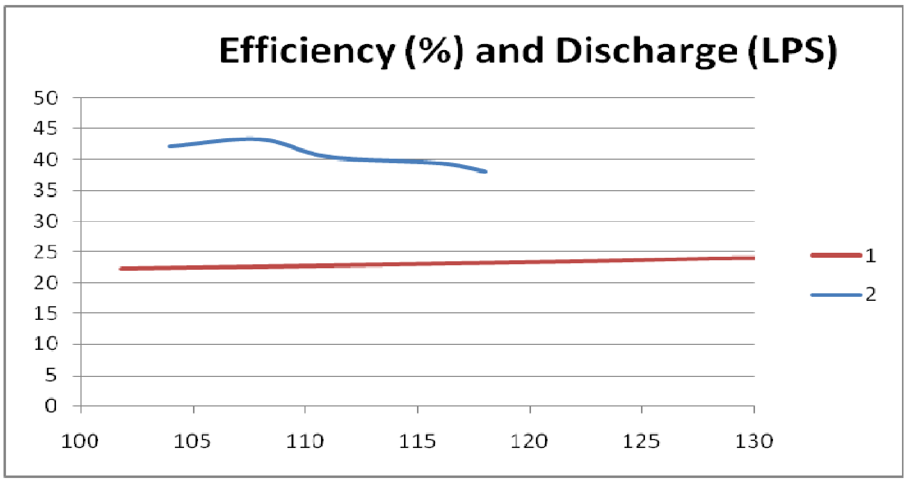


('Efficiency V/s Loading Curve' - Crossflow turbine testing)

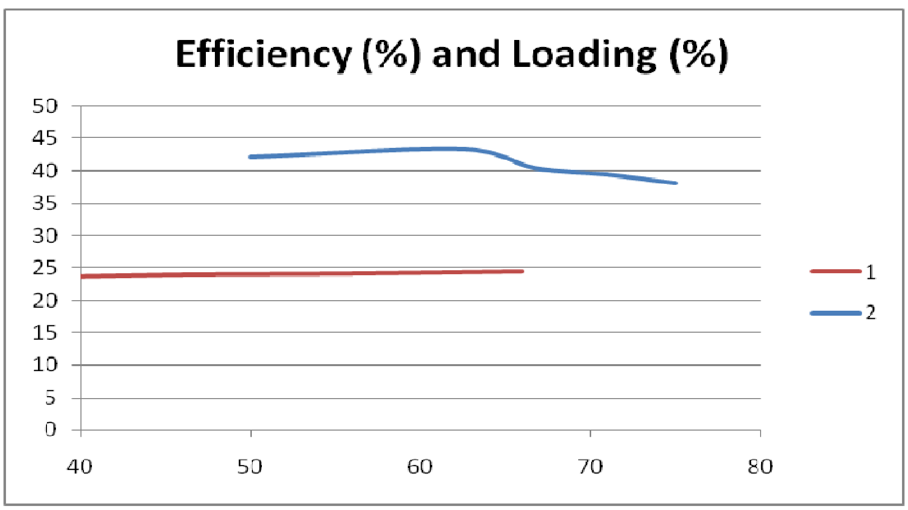
3.7.2 Axialflow turbine

		TURBINE 1					TURBINE 2				
Dischage	LPS	101.80	121.80	128.00	133.00	138.90	104.00	108.00	111.00	116.00	118.00
Head	m	2.16	5.01	6.13	7.07	7.91	2.78	3.28	3.64	3.80	4.08
Output	kW	0.60	1.75	2.30	2.80	3.30	1.50	1.88	2.00	2.13	2.25
Input	kW	2.15	5.97	7.68	9.27	10.76	2.84	3.47	3.96	4.32	4.72
Loading	%	12.00	35.00	46.00	56.00	66.00	50.00	62.67	66.67	71.00	75.00
Efficiency	%	22.24	23.43	23.94	24.16	24.54	42.25	43.34	40.40	39.44	38.13

(**Table 3.4:** Test Result of Axial flow turbine)



('Efficiency V/s Discharge Curve' - Axialflow turbine testing)

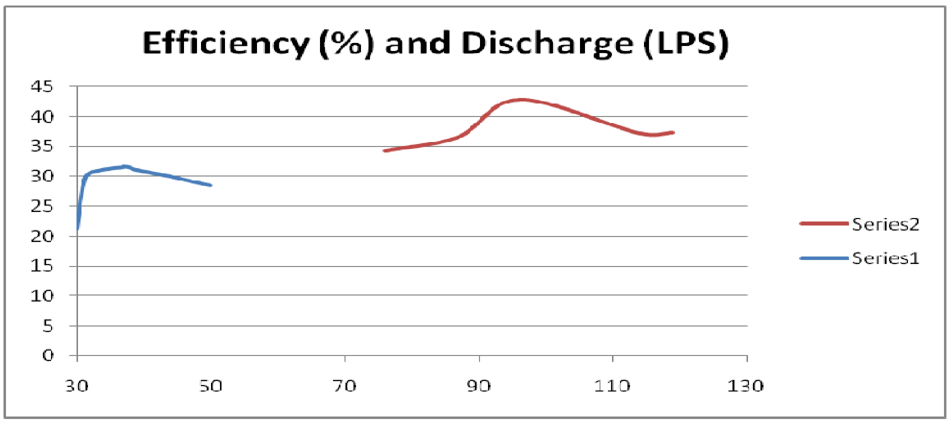


('Efficiency V/s Loading Curve' – Axialflow turbine testing)

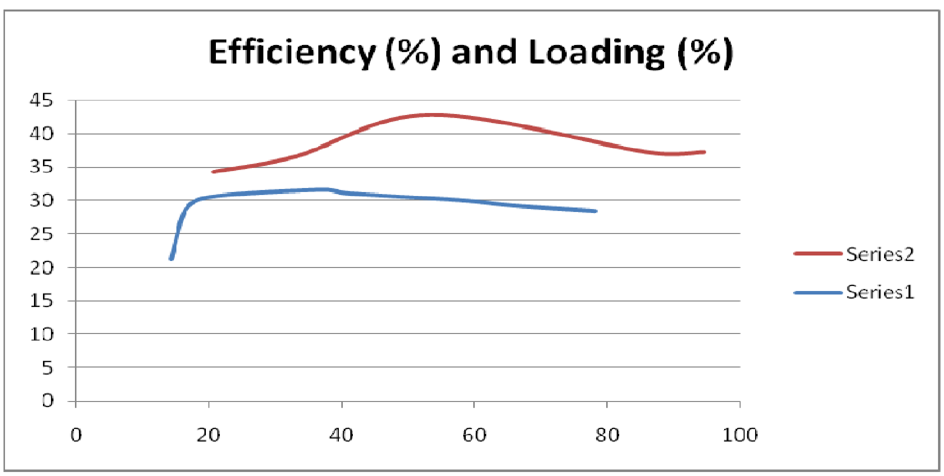
3.7.3 Pelton Wheel

		TURBINE 1					TURBINE 2							
Dischage	LPS	76	87	96	114	119	30	31	32	37	39	44	47	50
Head	m	2.9	3.8	4.8	7.5	7.8	8.3	8.3	9.8	14.4	15.5	20	22.1	25.5
Output	kW	1.03	1.65	2.67	4.32	4.73	0.72	0.83	1.03	1.85	2.06	2.88	3.29	3.91
Input	kW	2.16	3.23	4.49	8.35	9.12	2.44	2.58	3.04	5.27	5.97	8.61	10.11	12.36
Loading	%	20.6	33	53.4	86.4	94.6	14.4	16.60	20.60	37	41.2	57.6	65.8	78.2
Efficiency	%	34.344	36.648	42.84	37.224	37.296	21.312	28.71	30.6	31.59	31.05	30.06	29.25	28.44

(**Table 3.5:** Test Result of Pelton wheel turbine)



('Efficiency V/s Discharge Curve' - Peltonwheel turbine testing)



('Efficiency V/s Loading Curve' - Peltonwheel turbine testing)

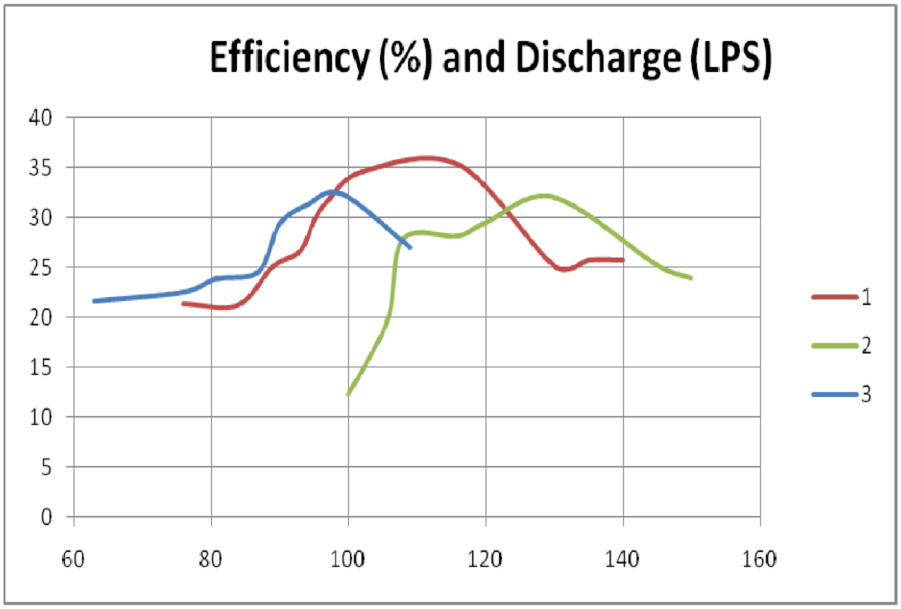
3.7.4 Improved Watermill

		TURBINE 1										
Dischage	LPS	76	84	89	93	95	97	102	116	130	135	140
Head	m	3.1	3.8	3.8	4.8	4.8	5.5	5.7	7	9.7	10.6	10.7
Output	kW	0.62	0.83	1.03	1.44	1.65	2.06	2.47	3.49	3.91	4.52	4.73
Input	kW	2.31	3.1	3.28	4.32	4.43	5.2	5.7	7.9	12.4	14.05	14.7
Loading	%	12.4	16.6	20.6	28.8	33	41.2	49.40	69.80	78.2	90.4	94.6
Efficiency	%	21.44	21.28	25.12	26.64	29.68	31.68	34.64	35.36	25.2	25.76	25.76

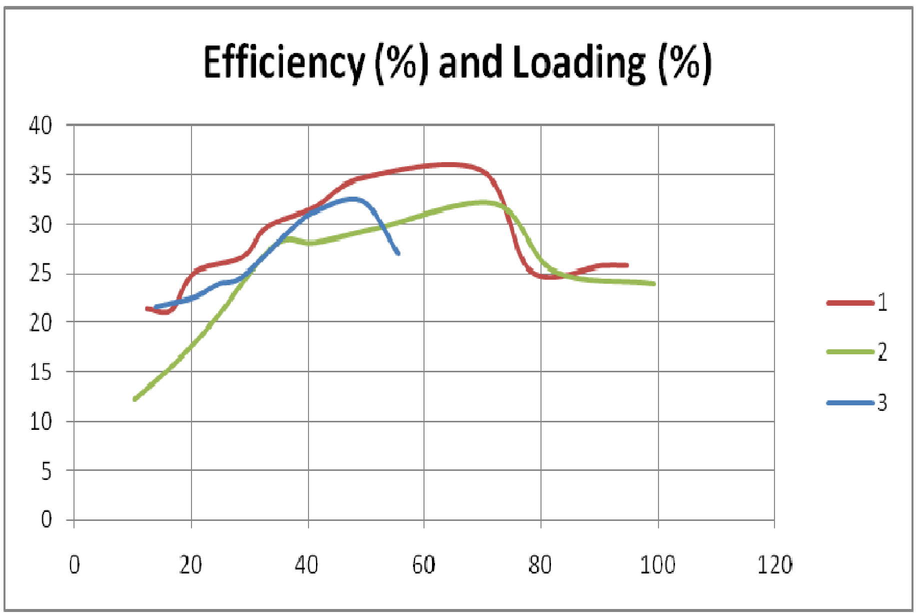
		TURBINE 2								
Dischage	LPS	100	103	106	108	116	120	130	145	150
Head	m	4.1	5.1	5.4	5.6	6.2	7.1	8.5	11	13.5
Output	kW	0.62	1.03	1.44	2.06	2.47	3.08	4.32	4.93	5.96
Input	kW	4.02	5.17	5.67	5.89	7.02	8.37	10.76	15.61	19.83
Loading	%	10.33	17.17	24.00	34.33	41.17	51.33	72.00	82.17	99.33
Efficiency	%	12.32	15.92	20.32	27.92	28.16	29.52	32.08	25.28	24

		TURBINE 3							
Dischage	LPS	63	76	81	87	90	94	99	109
Head	m	4.2	4.9	5.2	5.5	5.7	5.7	6.3	7.9
Output	kW	0.7	1.03	1.24	1.44	1.85	2.06	2.47	2.78
Input	kW	2.59	3.65	4.13	4.68	5.04	5.27	6.1	8.21
Loading	%	14	20.6	24.8	28.8	37	41.2	49.4	55.6
Efficiency	%	21.6	22.56	23.92	24.64	29.36	31.28	32.4	27.04

(**Table 3.6:** Test Result of Improved turbine)



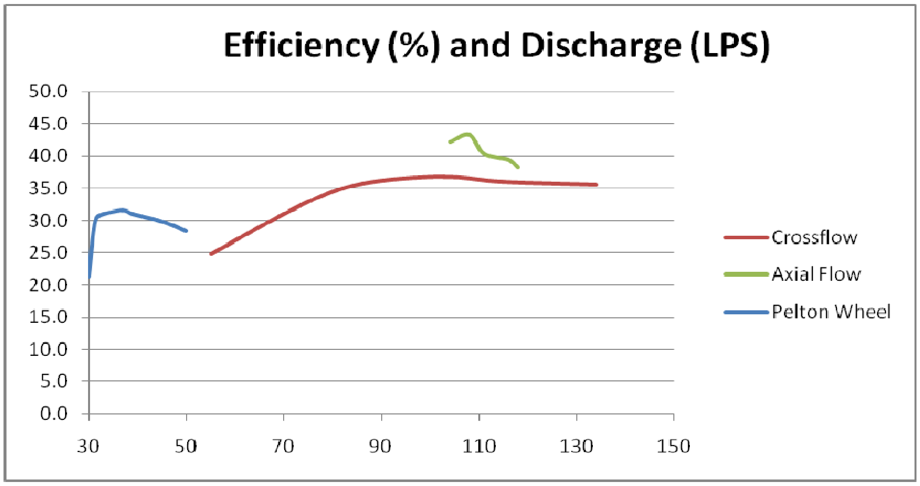
('Efficiency V/s Discharge Curve' – Improved Watermill testing)



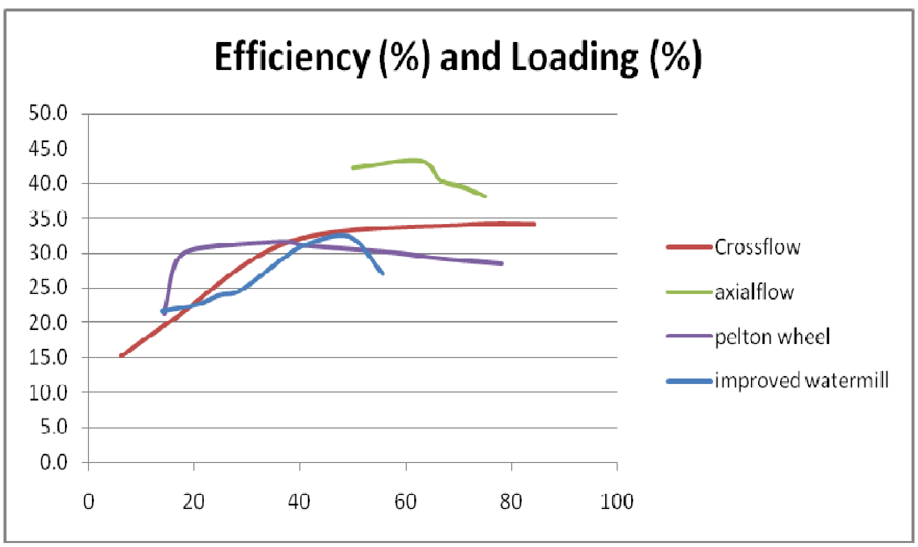
('Efficiency V/s Loading Curve' - Improved Watermill testing)

3.8 PERFORMANCE COMPARISON OF VARIOUS TURBINES

The percentage loading is calculated from the power output. From the graph it can be seen that crossflow and axial flow turbine maintain high efficiency for higher load (>50%) and so does the pelton wheel turbine for lower load (<30%). Therefore, this is an important factor for selection of turbine.



(‘Efficiency V/s Discharge Curve’ – Performance Comparision)



(‘Efficiency V/s Loading Curve’ – Performance Comparision)

3.9 IDENTIFICATION OF DESIGN IMPROVEMENT PARAMETERS

It is found that for low discharge (which is the case is majority of sites in Uttarakhand as shown by the survey) pelton wheel turbines are most suitable and for little higher discharge cross flow turbines gives the maximum efficiency.

Name of turbine	Discharge value for maximum efficiency
■ Crossflow	90 – 110
■ Axialflow	100 – 120
■ Pelton Wheel	30 – 60

Based on the test results of existing watermills as per previous chapter and other observations as per the survey finding following considerations have been taken in redesigning the watermill system.

Considerations:

Low cost, local material, minimum maintenance yet better efficiency, focus on points gathered from survey i.e. penstock, nozzle, trash, water control etc.

Design is based on low head and discharge as available in most parts of state as evident from survey. Most suitable turbine for the range of hydrological parameters in Uttarakhand is Pelton turbine.

Summary

- *Parameters of importance were identified in consultation with various stakeholders. Parameters ranged from hydrological, geographical to design and maintenance.*
- *Watermills are analyses and identified parameters covering all 13 districts and related information was also gathered from various stakeholders viz users, manufacturers, NGOs, government agencies and self help groups.*
- *Existing improved watermills were tested in the lab and observed that presently cross flow, axial flow and pelton turbines are used. It is also observed that for the same hydrology same type of turbines have huge differences in their efficiency due to improper and non standardization of design.*
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