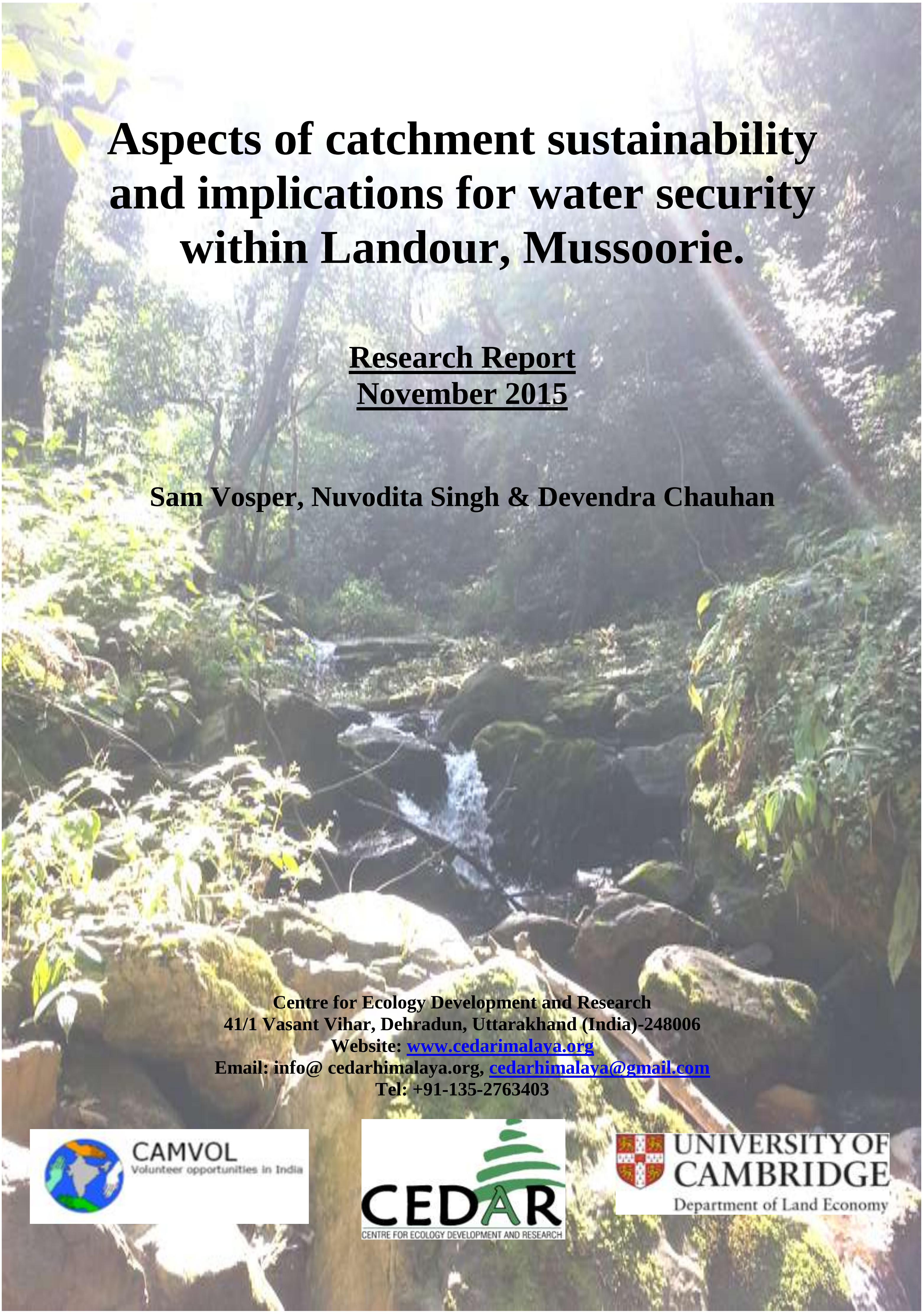

Aspects of catchment sustainability and implications for water security within Landour, Mussoorie.

Research Report
November 2015

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1. Background

The Mussoorie Township, also known as the "Queen of the Hills" is one of the famous hill towns situated in the Lesser Himalayas. Like many other hill towns, Mussoorie's population is solely reliant on water discharged from the surrounding springs and spring fed streams. The water discharged by these mountainous watersheds depends on numerous interacting factors such as; precipitation patterns, vegetation, soil, geology, topography and catchment area (Tiwari *et al.*, 2011).

The nature of these climatic, biological and geophysical factors can have an important bearing on how the quantities of water discharged are distributed in time and space (Negi & Joshi, 2004). Precipitation patterns in India are extremely seasonal with up to 50% of the annual rainfall falling over 15 days between June and September, the monsoon period (Briscoe and Malik, 2006). This typically results in temporally variable discharges from these watersheds and has historically led to the development of various adaptation and management strategies.

What makes Mussooorie an interesting case study is that the town's primary (and only) industry is tourism and the town's population near doubles in the peak tourist months which coincide with the leanest periods of water discharge (Ghildial, 2011). This spike in water demand coupled with a limited supply leads to a case of severe water shortage. The disaggregate arrangement of Mussoorie's water supply and distribution network presents a challenging situation when under water stress as not all areas are affected equally. This inequality is compounded by the fact that residents pay a nominal fee for water supply and are not metered and charged per litre of water used as with commercial connections.

The town is divided into four 'water zones' that are each supplied by specific pump and gravity schemes. Landour Depot is the most water deprived of the four zones (Jal Sansthan, 2015). The Landour Depot area has a permanent population of approximately 10,644 people (including the floating population of 2,000 people) and is thus home to approximately 20% of Mussoorie's permanent residents (Ghildial, 2011). This zone covers approximately 24% of Mussoorie's land area (15.5 km^2) which is inclusive of the Army Cantonment Area, Landour Ward no. 3 and Landour Ward no. 4.

The area is solely supplied by the Kolti pumping station which extracts water from the Kolti Khala (a perennial stream) at a constant rate of 0.72 ML/D (Jal Sansthan, 2015). However, the zone's water demand, based on 135 per person per day, is approximately 1.34 ML/D in the off season and 2.11 ML/D in the peak tourist season (although some papers present higher estimates). The water shortfall is thus 46% short of demand in the off season and 66% short in the peak tourist season. These figures are far higher than any other area in Mussoorie. Furthermore, Landour Depot is an area which is currently experiencing development which may exacerbate the water shortage in the future.

Figure 1: Elements of water security for a given population (Niven, 2015).

Considering Figure 1, it can be understood that, for a given population, water security is dependent on a number of elements. The appropriate management of these elements is key to ensuring an acceptable level of water security and livelihood sustainability for communities.

It is clear that a large portion of Mussoorie is dependent on a single water source and consequently the source's catchment area. For a situation such as this, it is important to be informed of any threats to water discharge and the appropriate management and monitoring practices that would be advisable. Thus, this study aims to assess the significant Kolti catchment area and explore some of the biophysical and human aspects that may affect the future sustainability of the stream's water discharge.

In doing so, this study will essentially focus on points; 1) Supply Capacity and 6) Environmental Limits, within the greater sphere of water security. However, this report hopes to form the basis of a larger study on water security and livelihood sustainability for the residents in Landour Depot where the remaining aspects are explored. The study also intends to present a methodology that may be applied to other water zones and catchment areas within Mussoorie and other hill towns.

2. Methods and Materials

This study has made use of field research, key stakeholder interviews and data available in governmental reports and published literature. The information gathered from these sources was used iteratively to inform the research process, with the findings then amalgamated into this report.

Firstly, a geographic position was recorded for the water extraction point at the Kolti pump station. This point was then used to plot a perimeter of the topographic catchment area which supplies the Kolti stream at the location of the pump station. This perimeter was created using satellite imagery from Google Earth.

The catchment boundary was used to inform field visits where on the ground assessments were conducted. These assessments involved the mapping of spring locations and private land boundaries as well as the identification of forest species, soil types and geological formations.

The catchment boundary and the identified private land owners helped inform the key stakeholder interviews regarding land use practices, historical changes in the catchment area and possible future threats to the area. In some instances the interviews were conducted within the field visits.

Other information regarding stream water discharges, water supply systems and infrastructural pump station upgrades were acquired from the regional water office, the Jal Sansthan. Further information on the pending legal cases relating to the development of forest and was sourced from the Supreme Court Monitoring Committee's (SCMC) office in Dehradun.

3. Discussion and Results

3.1 Catchment Geography and Water Discharge

Landour is situated in the most eastern section of the Mussoorie ridge with the catchment for the Kolti Khala falling to the northern side of the ridge. The topographical catchment area for the Kolti Pump Station is presented in Figures 1 and 2. The catchment covers an area of 2.34 km^2 with a perimeter of 6.11 km, a microwatershed (<5 km^2) (Tiwari *et al.*, 2011).

Figure 2: West facing view of the catchment area for the Kolti Pump Station.

Figure 3: South facing view of the catchment area for the Kolti Pump Station.

The Kolti Khala flows northwards towards Kolti Village which lies approximately 1km beyond the pump station. Below the village, the Kolti stream joins another stream know as the Kanda/Matholi stream which then continues north until it joins the Aglar River.

The catchment area is characterised by steep hills sides and gullies. The height differential from the base pumping station and the ridgeline varies between 550-650m, with the differential being a little above 650m at the ridge's highest point.

The Jal Sansthan's spot measurements of the water discharged from the Kolti stream is summarised in Table 1. The discharge of this perennial stream fluctuates from a low of approximately 750 LPM in June (peak summer season) and can reach a high of up to 3,000 LPM at times between August and November (Jal Sansthan 2015). It typically reduces to roughly 1,500 LPM from December to February.

Table 1: Water discharge measurements recorded for the Kolti Khala at the point of extraction (Jal Sansthan, 2015).

Kolti Khala Discharge at Pump Station 1 (LPM)			
Month/Year	**2012**	**2013**	**2014**
February	1300	1200	1000
June	800	750	730
October	2600	2500	2400

It does appear that the water discharge has been decreasing over the last three years. However, without historical rainfall data and more detailed information on how and when the measurements were taken it is not possible to discern what may have caused these changes and whether they are reason for concern.

The average rainfall data are available for Mussoorie and is summarised in Table 2. Considering Table 1 and 2 together it becomes clear that despite significant decreases in rainfall in the months following the monsoon (October – December) the water discharge is still at near its highest point. This suggests that the catchment area has a strong capacity to store water and releases it gradually. This is likely owed to the composition of the catchment's vegetation, soil and geology (Negi & Joshi, 2004).

Table 2: Average monthly rainfall for Mussoorie (Climate Data.org, 2015)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Rainfall (mm)	72	62	62	30	48	181	658	687	292	69	12	33

3.2 Geology and Soil

The greater Mussoorie area is dominated by limestone and dolomitic limestone (DMMC, 2013). While this rock type is highly soluble in water the solution action can be strongly selective. This leads to variable ground conditions that are typical of limestone areas.

The Jabarkhet – Kolti transverse (starting from Jaberkhet) is characterised by the presence of white quartzite, pebbly quartzite, micaceous sandy siltstone, shale, chert, phosphorite and limestone in most exposures (DMMC, 2013). It has been observed that the bedding is well developed in this section and that the rocks dip towards southeast to southwest at angles of 30°- 45° (moderate to moderately steep) (DMMC, 2013).

The direction of the bedding confirms that the catchment area for the Kolti Khala does follow the ridgelines as water would be unable to filter from the southern slopes as ground water.

Soils are a product of both the weathering of parent rock and the biological influence of vegetation. Raina & Gupta (2009) have studied and characterised a number of soil types in the Mussoorie area. They observed that the soils in forest areas where *Quercus leucotricophora* (Grey Oak) is dominant are clay loam in the upper soil layers and loam in the lower layers. The forests composed of *Pinus roxburghii* (Chir Pine) typically have a higher silt content with the upper soil layers being loam and the lower layers being silty loam.

It was also noted that the maximum water holding capacity (MWHC) of these two soil types differed. The clay soils were shown to have a marginally higher MWHC than the silty soils in both the upper and lower soil layers (Raina & Gupta, 2009). However, both these soil types had substantially higher MWHC than the soils found in barren land.

The higher MWHC of soils implies that they have a greater capacity to store water in the landscape and release it slowly over time. Considering this, it is advisable that the catchment remain forested to ensure that the distribution of water discharge continues in the lean rainfall months prior to the monsoon.

3.3 Vegetation

A vegetation cover distribution for the catchment area is presented in Figure 4. It shows that the catchment is dominated by densely forested areas and interspersed with section of very dense forest in the gullies. There are also two areas of open forest in the catchment, one on the western slope and one on the eastern slope.

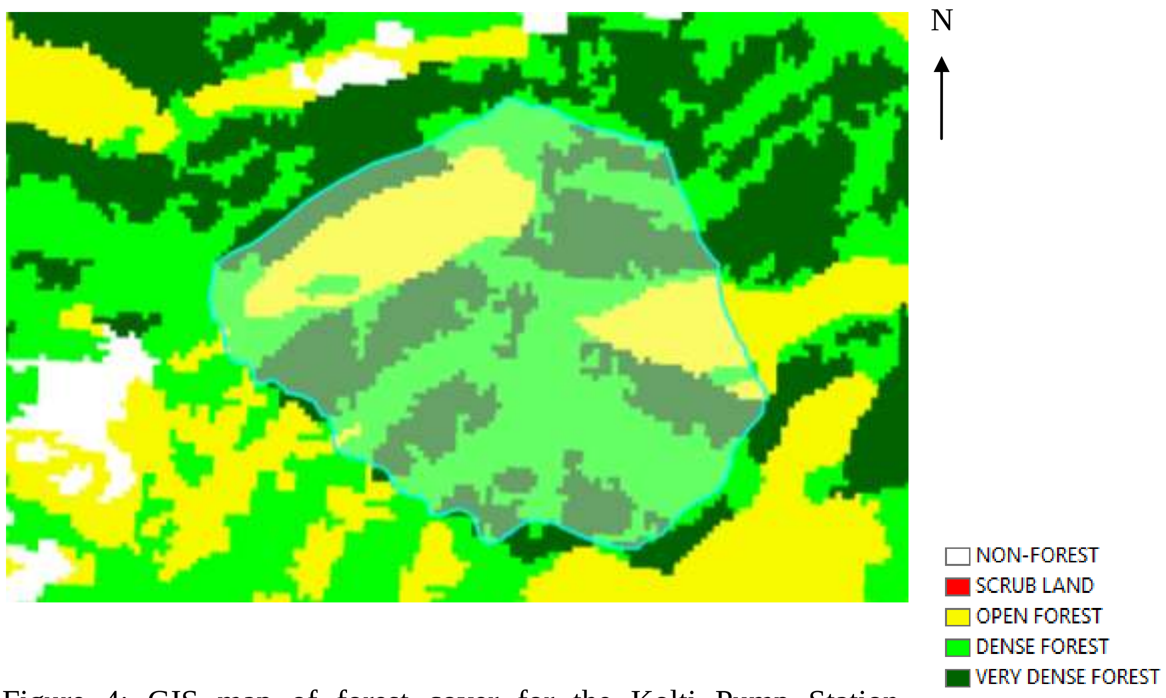

Figure 4: GIS map of forest cover for the Kolti Pump Station catchment area.

The patches of open forest are primarily composed of *Pinus roxburghii* (Chir Pine) and *Pinus Wallichiana* (Blue Pine). Consequently the litter cover is extensively made up of pine needles. The shrub layer in these areas is also particularly sparse.

The areas of dense and very dense forest are characterised by evergreen forest species such as; *Quercus leucotricophora* (Grey Oak), *Cedrus deodara* (Deodar), *Castanopsis indica* (Sweet Chestnut) and *Ilex dipyrena* (Himalayan Holly). The shrub layers below these trees are well developed with a large proportion of phanerophytes taking root. Some species include; *Girardinia diversifolia* (Himalayan Nettle), *Cornus macrophylla* (Large Leaf Dogwood) and *Cuscuta reflexa* (Dodder). Consequently, the litter cover is denser with a large store of nutrients.

From the site visit it was also apparent that there is a clear division between the pine and oak forests within the catchment. However, it was evident that some pine trees seem to be spreading into the intact oak forest. It was suggested by the resident nature guide that he did not think that the pine forest had spread and displaced the dense natural evergreen forest in recent years.

It is known that pine is a "fire-adapted but fire promoting-species" (Singh *et al.*, 1984). Oak forests are typically non-inflammable but can suffer damage from spreading pine forest fires (Singh *et al.*, 1984). In light of this, it can be speculated that the evergreen oak forest may come under serious threat if the pine forest does spread within the catchment and increase the chance of destructive forest fires.

While the soils associated with both pine and oak forests have a comparable MWHC, pine species are notoriously water intensive and are well known to reduce soil water content. Conversely oak forests are well known for being species that encourage ground water recharge (Ghimire *et al.*, 2014). Thus, in the interest of sustaining the water discharge from the catchment it would be recommendable to monitor the spread of pine and manage it if the oak forests come under threat.

3.4 Land Use and Ownership

The Kolti catchment lies exclusively within the Koti Kimoi Reserved Forest. However, there are a number of private entities that own sections of this forest land and fall within the boundaries of the catchment area. One of the largest sections of private land is the Jabarkhet Nature Reserve which is owned by the Jain Estate. This nature reserve covers approximately 0.45 km^2 (roughly 20% of the catchment). Other land owners include; Woodstock School, the Alter family of Oakwell Estate and Mount Herman (another private estate situated within the catchment area).

The areas managed by the Jabarkhet Nature Reserve and Woodstock School are used for nature walks and school excursions aimed at creating conservation awareness (Hanifl Centre, 2015). While small sections of the estates are residential a large portion of the land remains untouched forest appreciated for its aesthetic charm. There are two main paths through the catchment that link Kolti Village to Mussoorie and these are walked daily by villagers working in the town. Any grazing and planting done by the villagers is done in close proximity to the village and lies beyond the catchment area. Very few, if any, non-timber forest products are collected in the area.

Under the current land use and ownership schemes it would appear that the catchment area is not under any particular threat. For the most part it is in the interest of the private land owners to conserve the forest land as best they can.

3.5 Legal Dimensions

As the catchment area falls within the Koti Kimoi Reserve Forest it is still governed by the Forest (Conservation) Act 1980 (revised in 1988). This act limits the activities that may be undertaken in forest land even if it is privately owned and prohibits the use of the land for non-forest purposes unless otherwise approved by central government or another directing body.

Recently there have been a number of proposals to the State of Uttarakhand from individual land owners requesting ‘No objection certificates’ for the clearance of private forest land for the construction of residential buildings. These proposals have been referred through regional offices and the Supreme Court to the High Court of Uttarakhand in Nainital where they are currently pending a final decision. The cases will be assessed individually on their merit. However, approval will be subject to the fulfilment of the conditions that the construction is; a) domestic only b) less than 250m^2 c) limits tree felling to a minimum d) conserves soil e) and has all other regulatory approvals.

The majority of these cases were for developments in western districts of Mussoorie and none of the land owners within the catchment have pending residential developments. It was mentioned that the Jain Estate, the owners of the Jabarkhet Nature Reserve, had development plans for sections of their estate that fall outside the catchment area.

The legal dimensions governing forest land actively protect the valuable water provisioning services provided by the forest vegetation. However, the recommendation of this report is that if private forest land in this catchment is proposed for development it should not be approved as a precautionary measure to preserve water discharge from the Kolti stream.

3.6 Climate Change Projections

Projections from the PRECIS climate model, developed at the Hadley Centre (UK), anticipate increases in both rainfall and temperature for the Himalayan region (INCCA, 2010). When run for the 2030's the model predicts that the Himalayan region will receive an increase in average annual rainfall in the range of 5-13% (or 60-206mm) compared to the 1970's. It is expected that this increase will be experienced across all seasons with the largest monthly increases, of up to 12mm, occurring in the monsoon months of June, July, August and September.

The model also predicts that the Himalayan region can expect increases in temperature under all likely scenarios (INCCA, 2010). The projected net increases in air temperature for the 2030's range from 1.7 ^{o}C to 2.2 ^{o}C against 1970's values. The model outputs generally suggest that the temperature increases will occur across all seasons with exception of one scenario which predicts temperature decreases in the winter months.

These climatic changes are likely to have an impact on the composition and function of forests in the Himalayan region. However, these impacts are characterised by even greater uncertainty than the predictions of climatic change. Thadani *et al.* (2015) explain that changes in the seasonal temperatures and rainfall patterns can have a significant effect on the rate of leaf fall and seed germination of species in the lesser Himalayas. This in turn has important implications for the development of litter cover and forest regeneration.

It is postulated that the predicted narrowing of the seasonal temperature variations may promote the establishment of evergreen species (Thadani *et al.*, 2015). Temperature increases may also encourage the upward shift of lowland species and even some alien species. These species shifts may also be onset following forest fires that will become more likely with the persistently higher temperatures in the dry months (Parashar & Biswas, 2003).

The projected changes in climate (and consequently forests) do pose uncertain impacts for the discharge of water from the Kolti Khala. The expected increases in rainfall throughout the year are likely to increase the volume of water discharged from the stream in all seasons. This positive relationship between water discharge and rainfall is likely to persist if the forested areas remain dominated by evergreen species as anticipated. However, reductions in seasonal litter cover could reduce the biotic content and MWHC of soils which in turn may translate into less water storage in soils and less stream water discharge in the lean rainfall months. Furthermore, increased temperatures may stimulate higher rates of evapo-transpiration from trees and thus detract from the increases in water discharge. With the increased threat of forest fire the forested catchment area could be at risk of irreparable damage and consequently harm to the water supply.

In light of this threat and the uncertainties pertaining to the climatic and forest change it is advisable that the catchment area for the Kolti stream is included in a monitoring and risk reporting system.

3.7 Infrastructure and Developments

The Kolti pumping scheme was completed in 1971 and has thus long surpassed its 30 year design lifespan (Jal Sansthan, 2015). This scheme is comprised of a three stage pump system which currently supplies water to a number of reservoirs at a rate of 605 LPM for 20 hours a day. Due to its age the scheme suffers from frequent breakdowns which disrupt the water supply to Landour Depot.

In the event of these breakdowns the Jal Sansthan often diverts water from the Gun Hill pumping scheme. However, the diversions are often not pre-emptive and are frequently only executed following complaints of water shortage by residents. The relatively weak connectivity between the water zones of Mussoorie can result in inadequate levels water

pressure when redistributing water. The only solution is to periodically close off some lines to increase the pressure in others. As all residents pay a nominal monthly fee to receive water there are likely to be issues of water access equity with the systematic closing of lines.
Landour residents experiencing prolonged stoppages in water supply can sometimes collect (or purchase) water from other sources such as; commercial tankers, community taps or small public springs. Woodstock school in fact taps a spring located on their property which discharges 80-90 LPM. Two smaller springs are located in the Landour area and are accessible to the public, one near Jabarkahet Nature Reserve (4-10 LPM) and another near Oakwell Estate.

The Jal Sansthan has proposed a reorganisation of the Kolti pumping scheme which they hope will improve the water supply to Landour Depot. The plan is to implement a single stage pumping scheme that will lift 1,200 LPM from the same point in the Kolti Khala (Jal Sansthan, 2015). The upgraded scheme will follow the path of the existing pumping infrastructure and as such it is unlikely to compromise any of the forested areas of the catchment. While this scheme has not yet been approved it would still require approximately 18 months to complete once given the go ahead.

The major drawback of the scheme is that despite the proposed 1,200 LPM pumping capacity the maximum discharge of the Kolti stream in the lean months is approximately 750 LPM. This means that even with the construction of a balancing sump the scheme will only be able to lift 1.08 ML/D. This is significantly less than quantity of water demand by the permanent population (1.34 ML/D) and far less than that required when accounting for the tourist population in those months (2.11 ML/D). The scheme is expected to provide water to the whole permanent population of Landour Depot for the majority of the year (according to 2011 population estimates). However, it is evident that it cannot maintain this level of supply in the lean months. Considering this, it would seem that the proposed upgrade is rather conservative and short sighted in its attempt to only supply the current population for a portion of the year. Furthermore, the current proposal does not leave space for the permanent or tourist population to grow without continued water scarcity.

4. Conclusions and Recommendations.

In exploring the biophysical characteristics and human dimensions of the catchment area this report can conclude that there are currently no major threats posed to the future sustainability of Kolti Khala's water discharge. There is even the possibility that the water discharged from the stream may slightly increase with the increases in annual rainfall projected by climate models. However, such increases are characterised by great uncertainty due to the interaction of various other processes that may change within the catchment area such as the evapo-transpiration rates of forest species.

The threats indentified which include; the spread of water intensive species, the development of forest land and the increased risk of forest fires, do require monitoring and management despite their relatively low risk as the magnitude of their effect could be significant. However, if appropriate monitoring and reporting schemes were set up it is likely that that these risks could be mitigated for the most part.

While the catchment area and its water supply appears to be relatively stable it is clear that the proposed infrastructural upgrades to the Kolti pumping scheme are unable to meet Landour Depot's annual water demands even in the short term. Thus, this report recommends a different design for the upgraded pump scheme. The recommendation is that the Jal Sansthan should consider an alternative point of extraction for the primary pump station further down the Kolti stream as illustrated in Figure 5.

The suggested point of extraction is north of Kolti village where the Kolti stream meets the Kanda/Matholi stream. The stream at this point typically has a discharge of 2-3 times the discharge of the Kolti Khala. An ex-gram pradhan (village council member) of Kolti Village did not believe that there would be resistance to the placement of a pump station at that location as the villagers harvest water upstream and from hill side springs and the pumping infrastructure would not pass through village land. The catchment area for this point of the stream, at 12 km^2, is nearly 6 times larger than that for the current pumping station. The larger catchment area is likely not only to discharge greater volumes of water but also dilute the effect of any shocks to sections of the catchment area and thus increasing system resilience.

Figure 5: South facing view of the catchment area of an alternative site for a pump station.

While this report has made an assessment of the sustainability of Landour Depot's water supply in terms of its environmental limits, human impacts and infrastructural systems there are still many dynamics of water security to explore. This report has mentioned some of these issues, however their complexity does warrant further research. In terms of equal access and economic viability, it would be useful to better understand the dynamics how the risk of water security is distributed in the community and how this risk is perceived by its members. Furthermore, it would be instructive to assess the quality of water extracted under the current pump scheme as well as water from the site recommended in this report. In addition an analysis of the components that could be developed within the water system to increase its resilience and flexibility would also be very informative to decision makers and community members.

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