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# Groundwater resilience Nepal: Preliminary findings from a case study in the Middle Hills

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Open Report OR/14/069

IGB GROUNDWATER RESILIENCE

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OPEN REPORT OR/14/069

# Groundwater resilience Nepal: Preliminary findings from a case study in the Middle Hills

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*Front cover*

Landscape of the Middle Hills, Myagdi District, Nepal. © NERC 2014.

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This report is an output from the project *Groundwater resilience to climate change and abstraction in the Indo-Gangetic basin*

**Groundwater resilience to climate change and abstraction in the Indo-Gangetic basin** is a two-year (2012-14) research project strengthening the evidence-base linking groundwater resources, climate variability and abstraction in the Indo-Gangetic basin. This project has been funded by UK aid from the UK Government, and led by the British Geological Survey, however the views expressed do not necessarily reflect the UK Government's official policies. The project has two main aims:

- To develop a strategic overview assessment of the occurrence and status of groundwater resources in the Indo-Gangetic basin and develop a map of groundwater typologies spanning the groundwater system
- To strengthen the evidence-base linking groundwater resources, climate and abstraction through a series of four targeted case studies in the basin.

The project team involves researchers from the British Geological Survey, IIT Kharagpur, ISET-Nepal, ISET International, Meta-Meta, National Institute of Hydrology (Roorkee), Overseas Development Institute, University College London, University of Dhaka and Bangladesh Water Development Board.

For more information:

http://www.bgs.ac.uk/research/groundwater/international/SEAsiaGroundwater/

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The success of project also relied upon the cooperation of many different organisations; particular thanks are offered to our hosts ISET-Nepal and to IWMI, ICIMOD and the Groundwater Resource Development Board in Nepal for the useful discussions. Thanks also go to Minakshi Rokka Chhetri of ISET-Nepal and Linda Smith of ISET International for their support during field. Finally we extend our gratitude to the local communities within the study catchments for their assistance and advice, our particular thanks go to the local teachers and to Suman Pandey, Aum Pun and Prem Fakami for their help with the monitoring of the springs.

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# Summary

Groundwater resources in the Middle Hills of Nepal perform a major role in supplying domestic and irrigation water and in regulating river flows. However, there has been little systematic study of groundwater within the region, making it difficult to evaluate how water supplies and river flows may change in response to climatic and anthropogenic change. To begin to build an evidence base, two catchments in the Middle Hills were investigated. The aim of the study was to characterise the hydrogeology of the catchments, assess water supplies and water usage and evaluate how resilient groundwater may be to change.

Two contrasting sub-catchments within the Kali Gandaki River catchment were chosen: Ramche Village Development Committee (VDC), at an elevation of 2000 – 3000 m, with subsistence terraced farming and highly forested slopes, and Madanpokhara VDC which is largely below 1000 m, with expanding commercial agriculture. Groundwater sampling was undertaken during the post-monsoon season 2013 and pre-monsoon season 2014. Springs, tube wells and rivers across the two catchments were investigated using a combination of surveys, flow measurements, and sampling for inorganic chemistry, stable isotopes, groundwater residence time indicators (CFC and SF6) and noble gases. In addition, 12 months of weekly hydrological monitoring and monthly water usage surveys were undertaken at several sites.

There is a heavy reliance on springs for water supply in Ramche. The springs are typically perennial but with significantly reduced flows during the winter and pre-monsoon season. The springs have bicarbonate groundwater chemistry and generally low overall mineralisation. Springs issuing from the higher slopes are reliant on seasonal monsoon rainfall and snow to sustain higher flows, but baseflows are sustained by groundwater storage within the weathered aquifer and will therefore have some inter-annual storage. Discrete springs issuing from lower slopes are most likely to be fed from groundwater storage within the fractured aquifer network. Groundwater residence time indicators (CFC and $SF_6$) suggest a mean residence time of 10-20 years for pre-monsoon groundwater, implying inter-annual storage and therefore some built in resilience. However the general low storage of the groundwater environment suggests that none of the springs would be resilient to a long term reduction in precipitation.

In the lower catchment of Madanpokhara where floodplain and outwash deposits are present, many hand-drilled shallow tubewells have been installed in the last 5-10 years, decreasing the reliance on springs. The development of groundwater resources has resulted in a thriving agricultural co-operative, inward migration and a growing population. These shallow tubewells have increased the resilience of the water supplies to change but are potentially vulnerable to over-exploitation as a result of the rapid increase in abstraction. Groundwater sampled in tubewells along the margin of the floodplain is modern (~20 yrs Mean Residence Time (MRT)) with bicarbonate groundwater chemistry and no significant water quality concerns. Groundwater sampled from tubewells towards the centre of the floodplain appears to be older (~50 yrs MRT) with elevated concentrations of iron, manganese, zinc and arsenic detected at some sites.

With a growing recognition of the importance of groundwater storage in the Middle Hills there is significant potential to further advance the characterisation of groundwater systems and investigate the resilience of groundwater supplies to change. Systematic monitoring of groundwater, as springs flows, groundwater levels and chemistry would give a much better understanding of emerging trends. Likewise, monitoring current yields of springs and comparing to historic values at installation may allow some conclusions to be drawn about the trajectory of springflow. There are several groundwater-related initiatives underway within organisations in Nepal; the lessons learned from this current research, the methodologies used and the preliminary findings will be of value to these.

# 1 Project objectives

The valleys in the Middle Hills of the Himalayas may be some of the most sensitive areas to climate change in the Indo-Gangetic basin. Relatively small changes in temperature and the timing of the Asian monsoon could lead to significant variations in snow melt, runoff, and groundwater recharge with corresponding large impacts on water security. Meanwhile forecasts of increasingly inhospitable temperatures for lowland areas of Nepal and northern India (up to $60^oC$) are already leading to migration to the cooler Middle Hills, leading to increased demand for reliable water. Although future precipitation patterns and snow melt in the Middle Hills are poorly constrained, there is growing recognition that whatever the future may hold, groundwater storage within these catchments forms an important component of the Himalayan water budget (Andermann et al., 2012) and is vital for current and future secure water supply.

Limited research from river flows and water chemistry indicates a significant role for groundwater storage in the Himalayan foothills within fractured basement aquifers (Jenkins et al. 1995, Anderman et al., 2012). However, groundwater resources remains poorly characterised in terms of both the hydrogeological setting and water usage.

To begin to build an evidence base for the occurrence and behaviour of groundwater in the Middle Hills, two case study catchments have been investigated to evaluate the groundwater resource, assess the inter-connections with climate and river flow and to establish the degree of use of groundwater. Through these investigations the resilience of the water supplies to change, whether that change be climatic or anthropogenic induced, can be characterised.

The project had the following aims:

1. Provide an account of the groundwater resource situation in the Middle Hills through the characterisation of catchment water supplies and water usage. Assess the local perceptions of change and the evidence base for these.
2. Gain a better understanding of the hydrogeology of the catchments and wider hydrogeological setting.
3. To strengthen the evidence base through the collection of a reliable set of groundwater chemistry samples and groundwater residence times for two catchments within the Middle Hills.
4. Develop a better understanding of resilience of groundwater within the catchments and consider the likely response to change e.g. trends in migration and climate and consider the suitability of groundwater as a strategic resource for domestic and town supplies in mountainous areas.

The work was undertaken in the Palpa and Myagdi districts of Nepal by scientists from the British Geological Survey (BGS), the Institute of Social and Environment Transition (ISET) International and their sister organisation ISET-Nepal. The work undertaken in Nepal forms a case study within a two-year research programme funded by the Department for International Development (DFID), which aims to strengthen the evidence base linking groundwater resources, climate variability and abstraction with emerging policy responses in the Indo-Gangetic basin.

This report documents the main work carried out as part of this study and presents preliminary results and conclusions.

## 1.1 WORK PROGRAMME

The activities undertaken as part of this study and the periods over which they were undertaken are provided in Table 1.

| | |
|---|---|
| Apr-13<br>May-13<br>Jun-13 | Catchments in the Middle Hills are selected and background information on the hydrogeology and water resource situation is collated, through literature review and data mining exercise. An inventory of water sources is undertaken and sites for monitoring are identified. |
| Jul-13 | Long-term monitoring of spring sources for flow and temperature in the two catchments starts. |
| Aug-13 | Meetings between BGS, ISET and ISET-Nepal to finalise field work |
| Sep-13 | BGS and ISET-Nepal undertake first phase of field investigations in the two catchments, comprising surveys of the water sources and water usage, community interviews, groundwater chemistry sampling and the installation of groundwater level data recorders. |
| | Meetings are held with ICIMOD and IWMI in Kathmandu. |
| Oct-13 | Groundwater and stream water samples are submitted to the NERC laboratories for testing. |
| | Preliminary field report is prepared. |
| Nov-13 | IGB Project workshop in Delhi. |
| | Groundwater chemistry and stable isotopes results received from NERC laboratories. |
| Dec-13 | Review of laboratory results |
| Jan-14<br>Feb-14 | Water usage surveys undertaken (Jan-Mar). |
| Mar-14 | Groundwater-age laboratory results received from NERC laboratories. |
| Apr-14 | BGS and ISET-Nepal undertake second phase of field investigations in the two catchments, comprising surveys of the water sources and water usage, community interviews, groundwater chemistry sampling and the downloading and re-setting of groundwater level data recorders. |
| May-14 | Meetings are held with IWMI, GWRDB and DFID-Nepal in Kathmandu. |
| | Groundwater and stream water samples are submitted to NERC laboratories |
| | Presentation on Nepal project delivered at WASH conference at the Geological Society of London. |
| Jun-14 | Groundwater chemistry and stable isotopes results received from NERC laboratories. |
| Jul-14 | Nepal case study report submitted to DFID for sign-off. |
| Aug-14 | Field data and signed-off case study report to be provided to interested organisations and Nepal catchment communities. |
| Sept-14 | Presentation on the Nepal project delivered at the International Association of Hydrogeologists Annual Congress, Morocco. |

Background investigations — Data collection — Outputs and outreach activities

*Table 1 - Programme of work undertaken as part of the study*

All dates referred to in this report use the Julian calendar, where data were collected using the Nepali calendar dates were converted by ISET-Nepal.

# 2 Study area

Within this section we present an overview of the geographical and climatic setting of Nepal and a description of the geography of the Middle Hills. The final sections provide a more detailed account of Myagdi VDC and Ramche VDC within which the two study catchments are located. Two contrasting sub-catchments of the Kali Gandaki river basin were selected to represent some of the main hydrological, physiographical and socio-economic settings present within the middle hills. The first study catchment comprises the villages of Nangi and Ramche in Ramche VDC; lying at elevations of 2000 – 3000 m, this catchment relies on snowmelt contributions in addition to monsoon rain. The dominant land use type is community forest with most people employed in subsistence terraced farming. The second study catchment is situated in Madan Pokhara within Myagdi VDC. With elevations below 1000 m this catchment is both warmer and drier than Ramche VDC, with lower monsoon rainfall totals but with expanding commercial agriculture.

## 2.1 NEPAL

### 2.1.1 Topography

Nepal is located between the Ganga plains and the high Himalayan mountains. The country is characterised by a diverse topographical and physiographical landscape with elevations of less than 100 m above sea level (asl) in the Terai in the south of the Nepal through to 8,848 m asl in the high Himalayas in the north (NPC, 2010). The contrast in topography gives rise to different climatic regions ranging from summer tropical heat and humid conditions in the lowlands to alpine winters in the northern mountains. The country is divided into five major physiographic regions that extend across the length of Nepal: the Terai, the Siwalik Hills, the Middle Mountains, the High Mountains and the High Himalayas (Figure 1, Table 2).

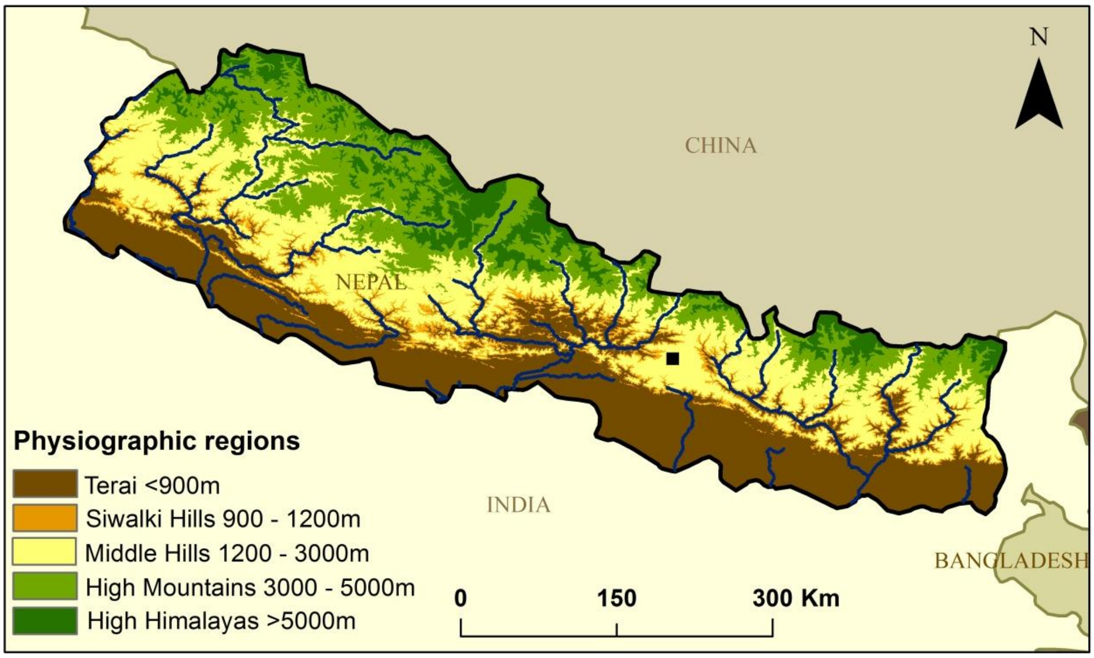



*Figure 1 - Physiographic regions of Nepal, derived from Shuttle Radar Topographic Mission (SRTM) topographic data USGS (2004).*

| Region | Elevations | Area | Geographic setting |
|---|---|---|---|
| Terai | <900m | 33% | The Terai region lies in the southernmost part of country. Land slopes gently southward and supports most of the country's agriculture. |

| | | | |
|---|---|---|---|
| Siwalik zone | 900-1200m | 8% | The Siwalik zone is located south of the middle mountain. It forms the first and lowermost ridges of the Himalayan Mountain system with cultivated valleys and plains. |
| Middle Hills | 1200-3000m | 30% | The Middle Mountain area comprises the country's central belt. This region is composed of networks of ridges and incised valleys. |
| High Mountains | 3000-5000m | 20% | The High Mountains are characterised by a series of ridges and mountain tops which are dissected by deep valleys and gorges incised to elevations around 1000 m asl. |
| High Himalayas | >5000m | 9% | The High Himalaya form Nepal's highest peaks and is largely covered by snow and ice throughout the year. |

*Table 2 - Description of the physiographic regions in Nepal.*

### 2.1.2 Climate

Nepal has a complex subtropical climate driven by the contrasting terrain and regional weather systems. The result is high temperature gradients across the country: from the hot plains to the cold mountains (Figure 2). Two climatic regimes dominate across the Himalayas – the westerlies, disturbances of which give rise to winter precipitation (Collins et al., 2013) and the monsoon system, with the latter most prominent in Nepal (Bookhagen and Burbank, 2010). The temperature gradient between the warm land (Tibetan Plateau) and cooler ocean is one of the main driving forces for the monsoon (Bookhagen and Burbank, 2010).

Long term average (LTA) annual precipitation varies spatially across Nepal from approximately 500mm to 2200mm (Figure 3). The majority of Nepal's total precipitation occurs during the Indian Summer Monsoon (ISM) (June-September), the source of precipitation coming from the Bay of Bengal with monsoon vortices moving to the north and northwest (Bookhagen and Burbank 2010). The south and east of Nepal generally receives more than 80% of its precipitation during the monsoon while the north and west of Nepal receives 55-80% (Shrestha 2000). Inter-annual rainfall variability is high and is thought to be linked to the Southern Oscillation Index (SOI), with deficits in rainfall associated with a negative departure from the SOI (Shrestha, 2000). Variations in the intensity and duration of the ISM caused by departures from the SOI can increase annual precipitation by approximately 25-50% at elevations below 3000m and by up to 200% in the high mountains (Andermann et al., 2012). Despite the inter-annual variability, trends in precipitation across Nepal's Himalayan headwaters for the period 1948-1994 have been consistent, with no observed reduction in precipitation (Collins et al., 2013).

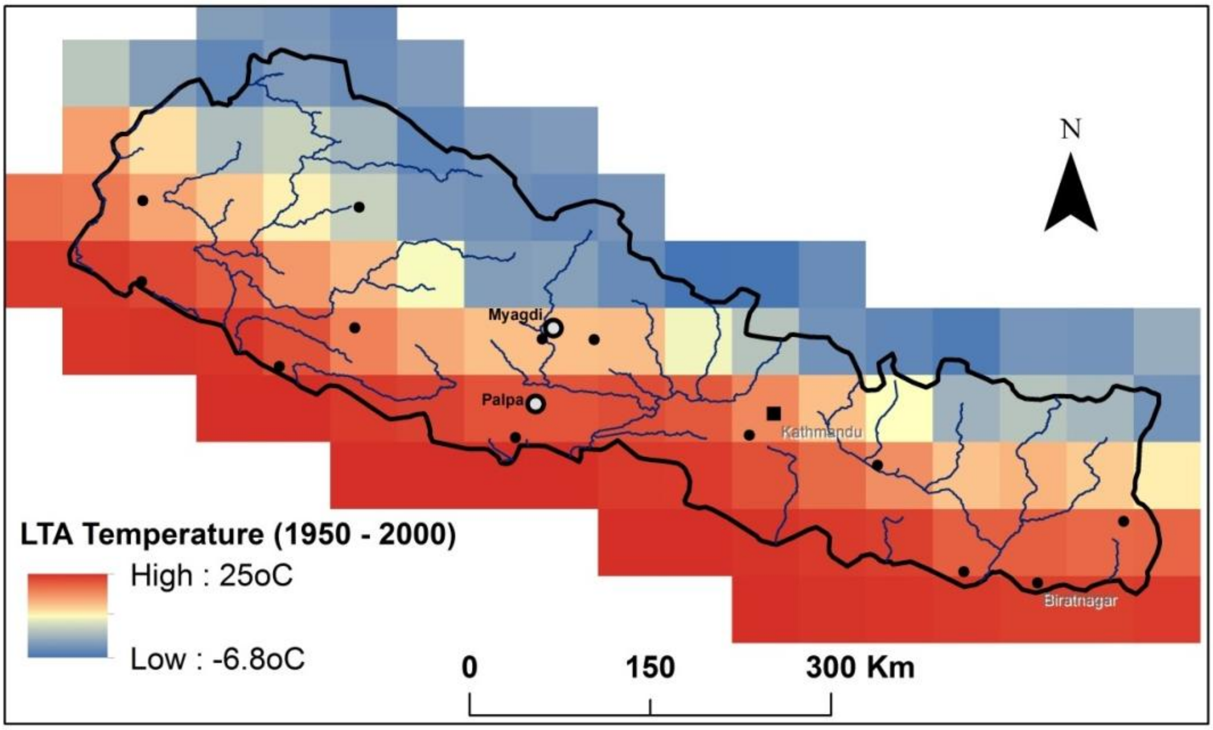



*Figure 2 - Long-term average (LTA) temperature for the period 1950-2000 derived from CRU data (Jones and Harris, 2013). The study catchments on Myagdi and Palpa districts are indicated by white circles.*

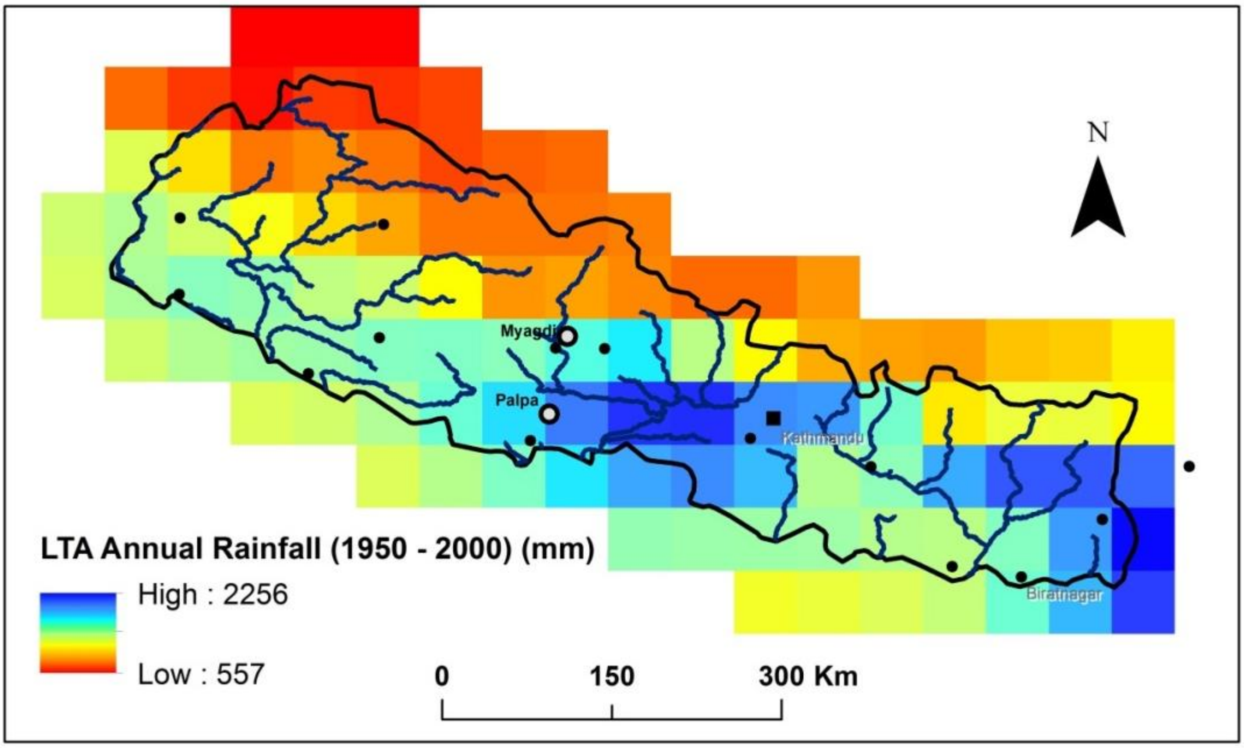



*Figure 3 Long-term average (LTA) precipitation (mm) for the period 1950-2000 derived from CRU data (Jones and Harris, 2013) . The study catchments on Myagdi and Palpa districts are indicated by white circles.*

### 2.1.3 Hydrology

Nepal's hydrological system is dependant not only on the ISM but also influenced by snow and glacier melt, and to a lesser extent by evapotranspiration (Andermann et al., 2012; Collins et al., 2013). It is estimated that glaciers in the Nepal Himalaya cover an area of more than 5000 km$^2$

and contain some 480 $km^3$ of ice. These glaciers cover approximately 3–4% of Nepal, and are located on, or near, the crest of the Himalaya, with the bulk of the ice at altitudes generally between 4000–6000 m asl (Mool *et al.*, 2001). The snow and glacier melt contribution to river discharge is estimated to be ~14 ± 7 $km^3$/year considering the three main catchments in Nepal (Sapta Koshi, Narayani and Karnali), which accounts for about 10% of annual river discharge (Andermann *et al.*, 2012). Glaciers in the central Himalayas are thought to have been reducing in length and thickness from the Little Ice Age maximum extension (Collins et al., 2013).

More than 6000 rivers and rivulets, with a cumulative length of 45000 km, dissect Nepal's landscape (WECS/DHMN 1996). The rivers rise from the lower Himalayas and flow to the Ganga plains in the south through a dense river network. These rivers cover around 3950 $km^2$ of the land surface (Khanal, 2001) with drainage density of about 0.3 km/$km^2$. About 1000 of the rivers are more than 11 km in length and as many as 100 are longer than 160 km. River flows in Nepal provide a vital source of water for hydropower, irrigation and water supply (Collins et al., 2013).

Nepal's river network largely extends across three main river catchments (Koshi, Narayani and Karnali). These catchments extend from the Tibetan Plateau to the lesser Himalayas with rivers sourced from glaciers, snow-fed glacial lakes and snow packs of the high Himalaya. These rivers drain about 78% of mountains section of Nepal and about 70% of the country (Bhusal, 2005). Some authors (Zollinger, 1979; WECS, 2011) sub-divide these river basins, distinguishing between those rivers and tributaries that rise from the glaciated portion of the catchment and those rivers which source from the Mahabharat range below the snow line. The significant contribution of monsoon rainfall to river flows across the expansive lower slopes of the Middle Hills is recognised (Collins et al., 2013). The groundwater storage and contribution to river flows across the Himalayan hills is not accounted for in Nepal's hydrological budget (e.g. Bookhagen and Burbank 2010; Moiwo et al., 2011; Collins et al., 2013) though recent investigations suggest groundwater storage in the fractured basement aquifers may be significant (Andermann et al. 2012).

Smaller, isolated, river catchments are present in the south of Nepal where rivers source from the Siwalik Hills in front of the Himalayan range. These rivers have a flashy response and are responsible for triggering flash floods during the monsoon. These rivers have low flows along their upper reaches during the dry season and offer little potential for generating hydropower.

The spatial and temporal distribution of precipitation varies significantly because of the contrasts in topography and is reflected in the river flows. Maximum river flows occur during July-August coinciding with the peak of the monsoon declining through to minimum flows in February-March. River flow hydrographs for the main river types in Nepal are presented in Figure 4, along with the locations of the gauging stations.

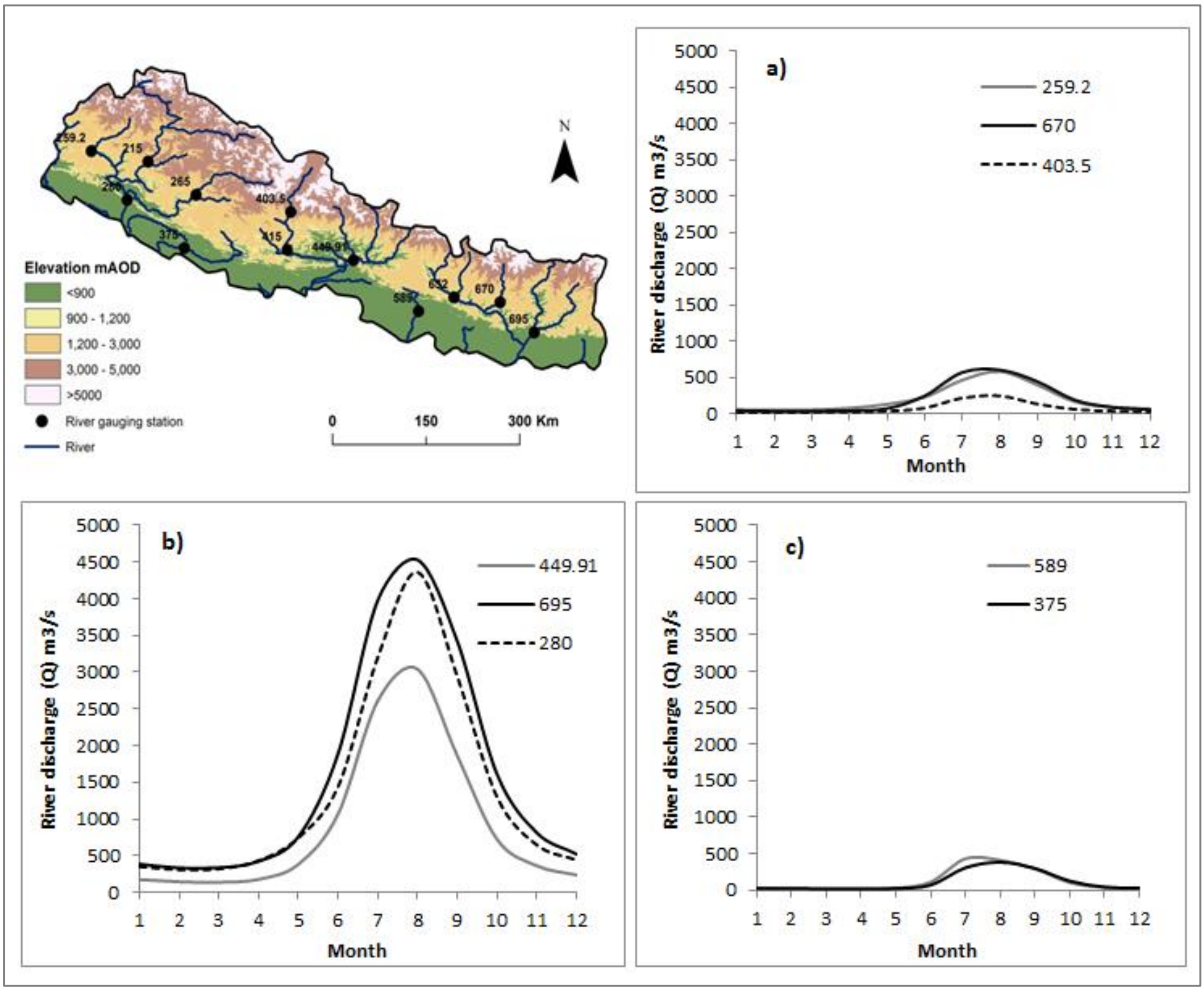



*Figure 4 - River flow hydrographs for the main river types in Nepal a) tributaries rising from the high mountains and Middle Hills b) main rivers downstream of tributary confluences c) small rivers rising from the Siwalik Hills. Gauging station numbers and locations are indicated. River flow data provided by Department of Hydrology and Meteorology, Nepal. Elevation data USGS (2004) Shuttle Radar Topography Mission.*

Some of the rivers pre-date the uplift of the main Himalayan ranges and have kept pace with the rate of uplift cutting through the ranges to form deeply incised valleys. In the mountainous and Middle Hill regions the lower permeability geology and steep slopes tend to promote rapid run-off resulting in a dense network of small, steep streams that drain into major tributaries. In contrast, in the Siwalik region, the less rugged terrain and more permeable geology promotes groundwater recharge of the aquifers in the Terai.

### 2.1.4 Geology

Nepal is located in the central part of the Himalayan arc, the geology is relatively young and tectonically active and the mountain range is characterized by high mountains dissected by deep river valleys undergoing constant landscape evolution (Figures 5 and 6).

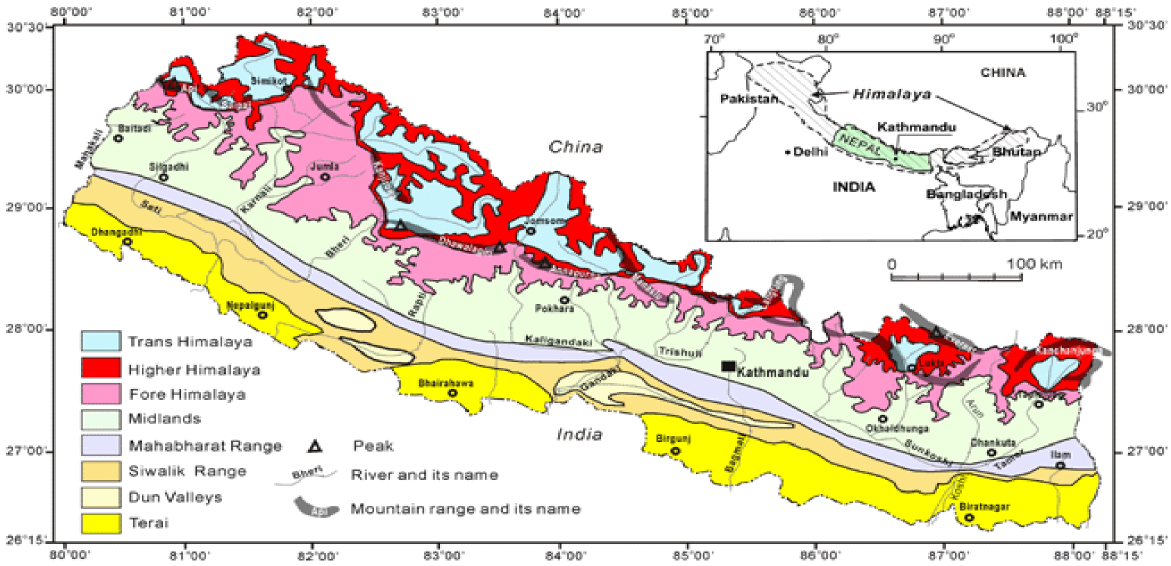



*Figure 5 – Geomorphological setting within Nepal. From Dahal (2010).*

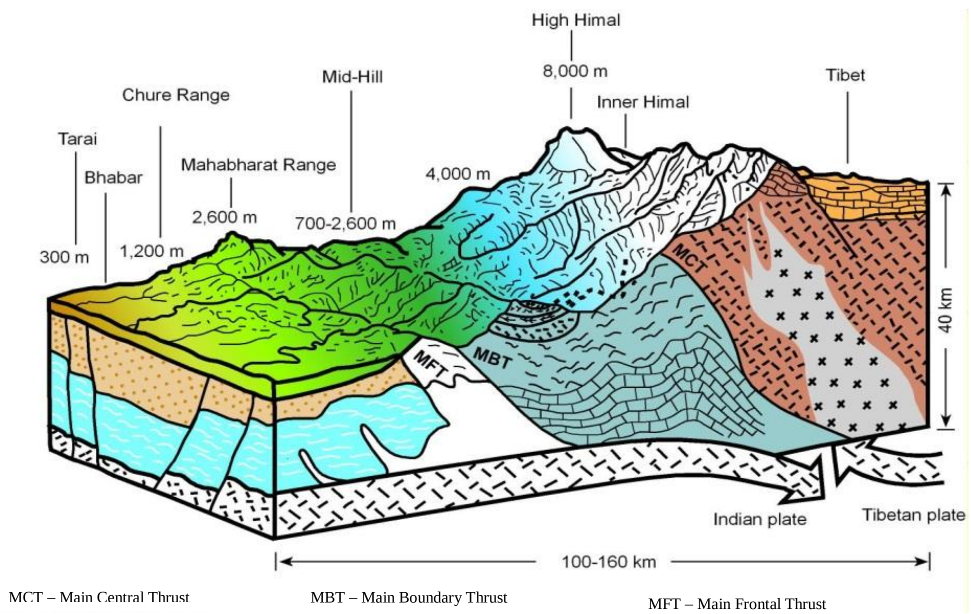



*Figure 6 - Geomorphological division of Nepal, modified from Hagen, T. (1998).*

Nepal can be divided into five tectonic zones from north to south: the Tibetan-Tethys Himalayan Zone comprising low-grade Paleozoic-Mesozoic Tethyan Sediments, Higher Himalayan Zone formed of high-grade metamorphic gneisses and migmatites, Lesser Himalayan Zone comprising low-grade Proterozoic sediments (Mahabharat Range and mid valleys), Siwalik Zone composed of mudstone and sandstone sediments, and the Terai Zone formed of unconsolidated alluvial sediments. These are broadly equivalent to the five major physiographic regions (Table 2). Each of the geological zones is characterized by its own structure and geological history and separated from each other by thrust faults. The southernmost fault, the Main Frontal Thrust (MFT) separates the Siwalik Zone from the Gangetic Plains. The Main Boundary Thrust (MBT) separates the Lesser Himalayan Zone from Siwalik. The Main Central Thrust (MCT) separates the Higher Himalayan Zone from the Lesser Himalayan Zone. The South Tibetan Detachment System (STDS) marks the boundary between the Higher Himalayan Zone and the overlying sedimentary sequence of the Tibetan-Tethys Himalayan Zone (Figure 6).

Owing to the rugged topography, complex geological settings, soft soil cover, high intensity rainfall during monsoon periods and frequent earthquakes, landslides, debris flows, soil erosion, and other mass wasting processes are common natural hazards in Nepal (Bartlett et al., 2010).

## 2.2 MIDDLE HILLS

The Middle Hills of Nepal, known as the Lesser Himalayas occupy 65% of the land area of Nepal (Gautam, 1993). Its average altitude is 2,000 m asl with elevations ranging from 600-3,500 m asl (Nepal Biodiversity Strategy, 2002). Topographically the region shows extreme rugged terrain with very steep slopes and deeply incised valleys. The Middle Hills exhibit a more mature landscape compared to other regions at lower altitudes with wide valleys. A large network of rivers and streams drain the Middle Hills, these rivers carry high sediment loads with evidence of deposition along many reaches. Due to the presence of Mahabharat Range in the south which forms a topographic high, most rivers flowing across the Middle Hills are deflected to follow a east-west oriented course collecting discharge from many north-south flowing tributaries. Extensive terraces have formed along rivers in the Middle Hills where the course of the river occupies a low gradient. A few rivers such as Sapta Kosi in east Nepal, the Narayani in central Nepal, and the Karnali in far-western Nepal, rise from the high Himalayas and flow though this Middle Hills forming some of the deepest gorges in the world.

Geologically, this region is made up from unfossiliferous sedimentary and metasedimentary rocks such as shale, sandstone, limestone, dolomite, slate, phyllite, schist, and quartz. The rocks are of Precambian (as old as 1,800 million years) to Eocene (about 40 million years) in age (Upreti, undated). The rocks in this region are highly folded and faulted, with a complex geological structure.

*Figure 7 - Typical landscape of Nepal's middle hills ©ISET 2014.*

The climate varies from subtropical at lower elevations and in the valley floors through to warm temperate conditions at higher elevations and on mountain ridges. During summer the temperature reaches an average of 32$^{o}$C. Winters are cold and temperatures sometimes reaches -1$^{o}$C (Shrestha et al., 1999). Annual precipitation in the Middle Hills varies from less than 1000 mm in the east and west extremities of Nepal's Middle Hills to more than 3500 mm in the central Middle Hills (Shrestha, 2000). The Middle Hills typically receive 70-80% of precipitation during the monsoon season. Rivers in the west, which receive less rainfall, are more dependent on snow-melt from the higher Himalayas.

The Middle Hills and mountain regions are believed to have a lower groundwater potential than the main groundwater basins present in the Terai and the mid-hill valleys, such as Kathmandu and the Dang, where groundwater is used extensively for agriculture, industry and water supply. Groundwater resources in the Middle Hills have not been systematically investigated and very few estimates of the groundwater resource exist. However, investigations by Kansakar (2002) suggest the annual groundwater recharge in Nepal's mid-hills is 1,723 million cubic metres and Andermann et al. (2012) conclude that groundwater storage within the fractured basement aquifers of the Middle Hills significantly influences river discharge. Groundwater discharge occurs in the form of springs and seepages and plays a critical role in the lives of the people in the hills. In some mountain areas it is the only source of water for drinking and irrigation.

Springs also help maintain baseflow in rivers, and sustain aquatic ecosystems. Groundwater resources are more limited because of the presence of low permeability crystalline basement and steep slopes which promote increased run-off and reduce the potential for groundwater recharge. However groundwater in the slopes of the Middle Hills is likely to occur within the weathered bedrock zone and within fractures in the underlying basement aquifers. Fluvial sand and gravel aquifers deposited within both the active and former river floodplains are also likely to store significant groundwater resources.

The majority of the population lives in the Middle Hills with very dense populations in the Kathmandu, Pokhara, Trishuli and Banepa valleys (Figure 8). Major economic activities include agriculture, tourism, trade, service and micro-enterprises. The people in this region have prospered from the growth in the tourism industry. Agriculture is intensive in this part of the country where farming occurs on terraces built into the hillslope, sometimes up to the very tops of the high hills. Forests have been severely degraded in this region and exploited for the purpose of fodder, firewood, litter and timber collection. The rate of soil erosion is a significant concern as a result of deforestation.

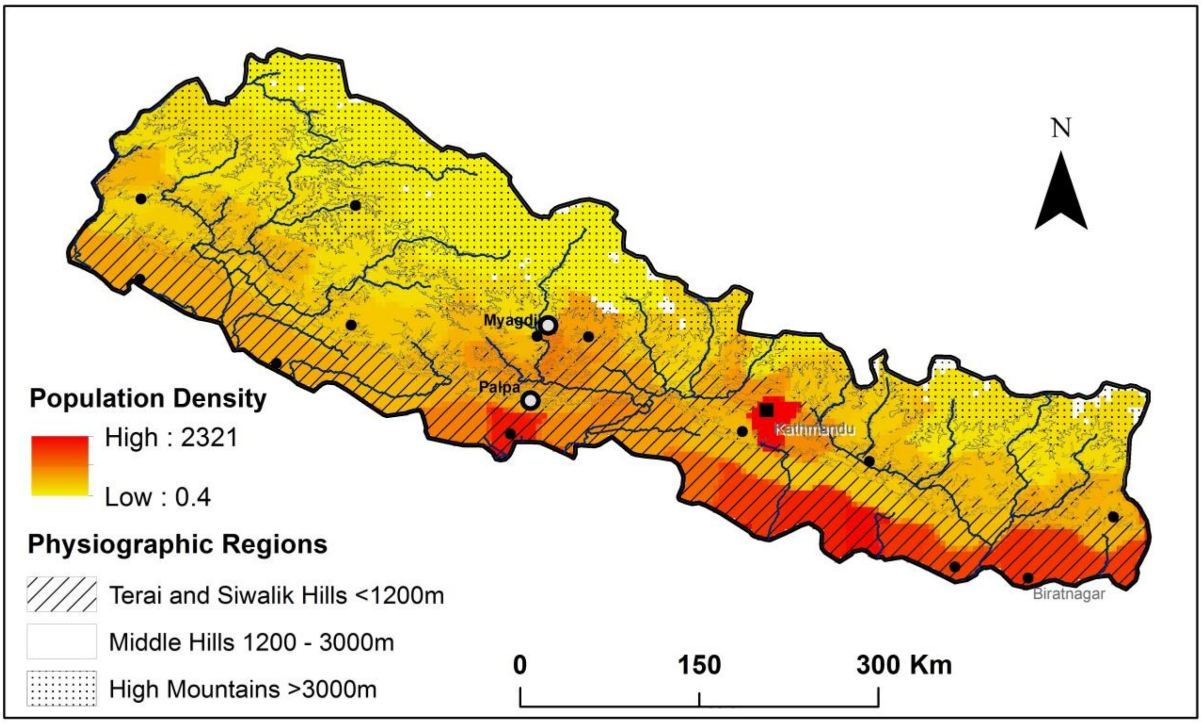



*Figure 8 - Nepal's population density with the physiographic regions overlain. Global population density data Center for International Earth Science Information Network (CIESIN), Columbia University and CIAT http://sedac.ciesin.columbia.edu/gpw. Physiographic regions of Nepal, derived from Shuttle Radar Topographic Mission (SRTM) topographic data USGS (2004).*

Nepalese agriculture in the hills and mountains is affected by soil erosion due to the steep gradients and intense monsoon rainfall, leading to reduced soil fertility and declining agricultural productivity. While it has not been possible to quantify current losses, the cumulative effects are likely to reduce annual agricultural production by several per cent in the cultivated

*Figure 9 - Typical terrace farming on hillslopes in the middle hills ©NERC 2014*

areas of the hills and mountains (Government of Nepal, 2012).

Inter-annual climate variability also affects agriculture, which is predominantly small-scale and heavily dependent on natural rainfall, leading to large annual variations in production. In addition, floods and droughts have large impacts on agriculture.

The Middle Hills embodies a vast ecosystem and diversity of species. Spotted leopard, barking deer, and Himalayan black bear are some of the common wildlife. The region is home to four hundred species of bird. In many areas of this region ecosystems have become increasingly stressed due to the dual pressures from rural and urban demands, for example, land degradation, pollution and over-exploitation of resources.

## 2.3 RAMCHE AND NANGI VILLAGES, MYAGDI

### Location

Ramche Village Development Committee (VDC) is one of the most progressive VDCs in Myagdi district. VDCs are a local level municipality with the purpose of structuring the village community to create strong partnerships between the community and the public sector. Myagdi district is located in the Western Development Region of Nepal (Figure 10). Its altitude ranges from 792 m asl (Ratnechaur VDC) to 8167 m asl (Dhaulagiri Himal). Covering an area of 2,297 $km^2$ (22,9,700 ha), Myagdi district is surrounded by Manang, Kaski and Parbat districts in the east, Baglung and Rukum districts in the west, Dolpa and Mustang districts in the north and Baglung district in the south. The district's headquarters are in the town of Beni.

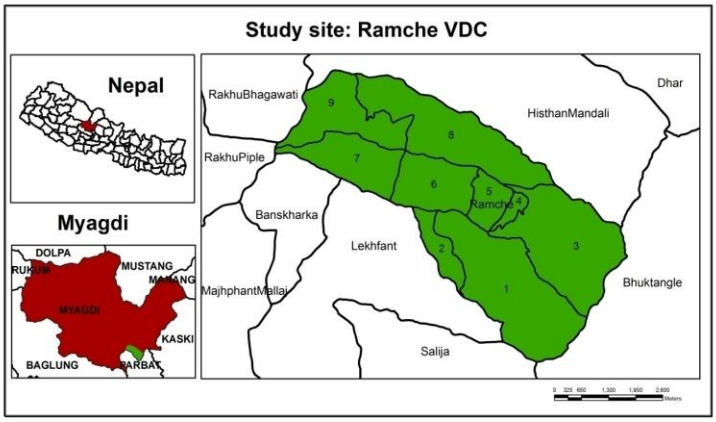



*Figure 10 - Map showing the location of Ramche VDC and wards.*

Ramche VDC lies at the edge of the south eastern part of Myagdi district, with altitudes ranging from 950 to 3,263 m asl. The VDC has Histan VDC to the north, Rakhu Bhagwati VDC and Rakhu Piple to the west. The eastern and southern part of this VDC is surrounded by Parbat district. The major vegetation found are Rhododendron, Walnut (*Juglans regia*),Chestnut (*Castonopsis indica*), Emblic myrobalan (*Emblica officinslis*), Chebulic myrobalan (*Terminalia chebula*) and Belliric Myrobalan (*Terminalia bellrica*) (Dixit and Khadka 2013).

### Land use

Ramche has total land area of approximately 2,600 ha (based on DOS, 1993). About 89% of total land cover is forested. The forest has improved in condition since community forestry was initiated and shifting cultivation was banned. About 220 ha is arable and is mostly *bari* land (non-irrigated agriculture land). The VDC has no *khet* land (irrigated terrace). Shrubs and grazing land are other forms of land use in Ramche. Table 2 shows the areas covered by each land use and percentage of its coverage.

| Land use | Area (ha) | Percentage |
|---|---|---|
| Agriculture land | 220 | 8.5 |
| Forest land | 2,320 | 89.2 |
| Grass land | 8.8 | 0.34 |
| Shrub land | 36 | 1.38 |
| Barren land | 5.2 | 0.2 |
| Water body | 11.7 | 0.45 |

*Table 3 - Land use in Ramche VDC. Source: Values derived from DOS (1993)*

### Climate

Myagdi district has four different types of climate ranging from sub-tropical to alpine. The annual average maximum rainfall is 2,960 mm and annual average minimum 407 mm. The mean annual rainfall trend of Myagdi district is presented in Figure 11. The recorded annual average maximum temperature is 36$^{o}$C and annual average minimum temperature is 3$^{o}$C. The lower parts of Ramche VDC have a warm temperate climate, while the upper hills experience a cool temperate climate. There are three distinct seasons i) cool winters with both snowfall and rainfall ii) pre-monsoon season or spring with periodic thunder showers and iii) summer monsoon season. The climate in Ramche is favourable for growing pears and citrus fruits. Seven different types of rare Rhododendron are found here.

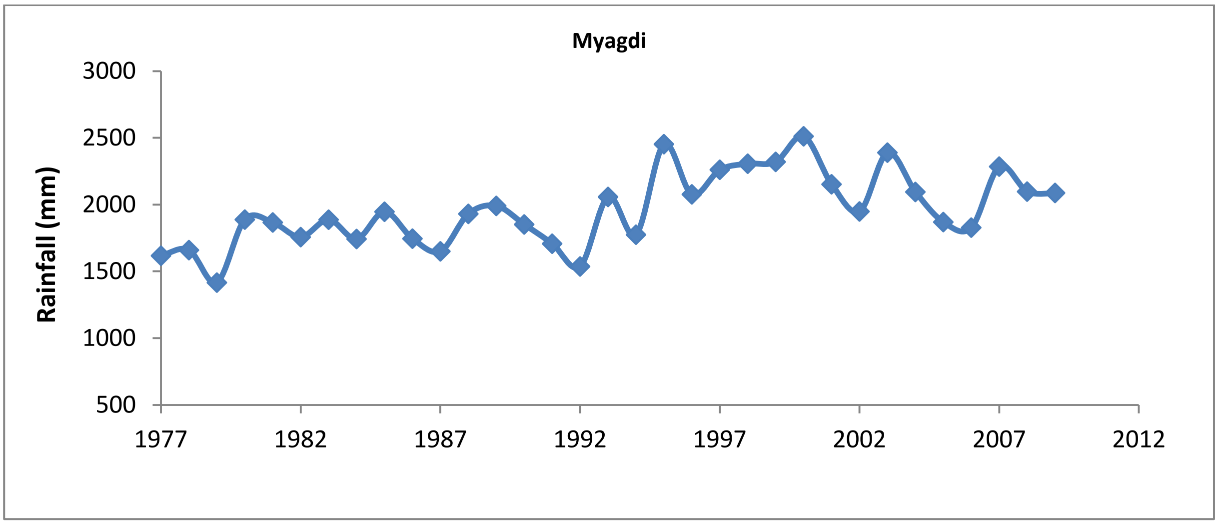



*Figure 11 - Mean annual rainfall trend of Myagdi district (temperate datasets). Rainfall data Department of Hydrology and Meteorology, Government of Nepal, gauging stations 619, 621, 626, 627, 628, 629.*

A rise in temperature has been observed in Myagdi and local people report an increase in pests and diseases over the years where stem borer and aphids have attacked maize plants. Potato, the major crop of Ramche, is affected by insect species locally known as Rato Dhamira, Khumara and Baiselo. Another local species, Tame is seen in barley. Elephant beetle and larvae also affect vegetable crops. Locals also report changes in planting and harvesting schedules. Warmer temperatures have however made the climate suitable for new crops and vegetables. People within Ramche have recently started planting vegetables such as tomatoes, cauliflower, cabbage and mushroom.

Anecdotally locals report increased rainfall within Myagdi, causing increased disruption to transportation affecting mobility. The impact of landslides and floods on local initiative of food production and vegetable farming as a result of increased rainfall is also a concern.

**Population and Literacy**

Ramche VDC covers an area of approximately 2600 ha and has a total population of 1,600 with 708 male and 892 female in 460 households (CBS, 2011). Ramche VDC has a literacy rate of 85.27%, with 48.5% male literacy and 51.5% female literacy (CBS, 2011). The VDC has two schools including one higher secondary school. The higher literacy rate in Ramche is also because of the availability of informal education (*Proudh shikchhya*) in the VDC.

**Economy and Livelihood**

Agriculture is the major source of livelihood in almost all villages of Ramche, however, food sufficiency, when communities are able to meet consumption needs from their own production, is less than a year in the VDC. The villagers are engaged in various off-farm income generating activities to sustain their livelihoods, including services, business, armed forces and small cottage industries. Some have migrated out of the village or country to seek work opportunities. A reduction in a skilled agricultural workforce is reported to be one reason why less land is used for agriculture. Tourism is gradually growing in the VDC. Income from these off-farm sectors helps support local livelihoods.

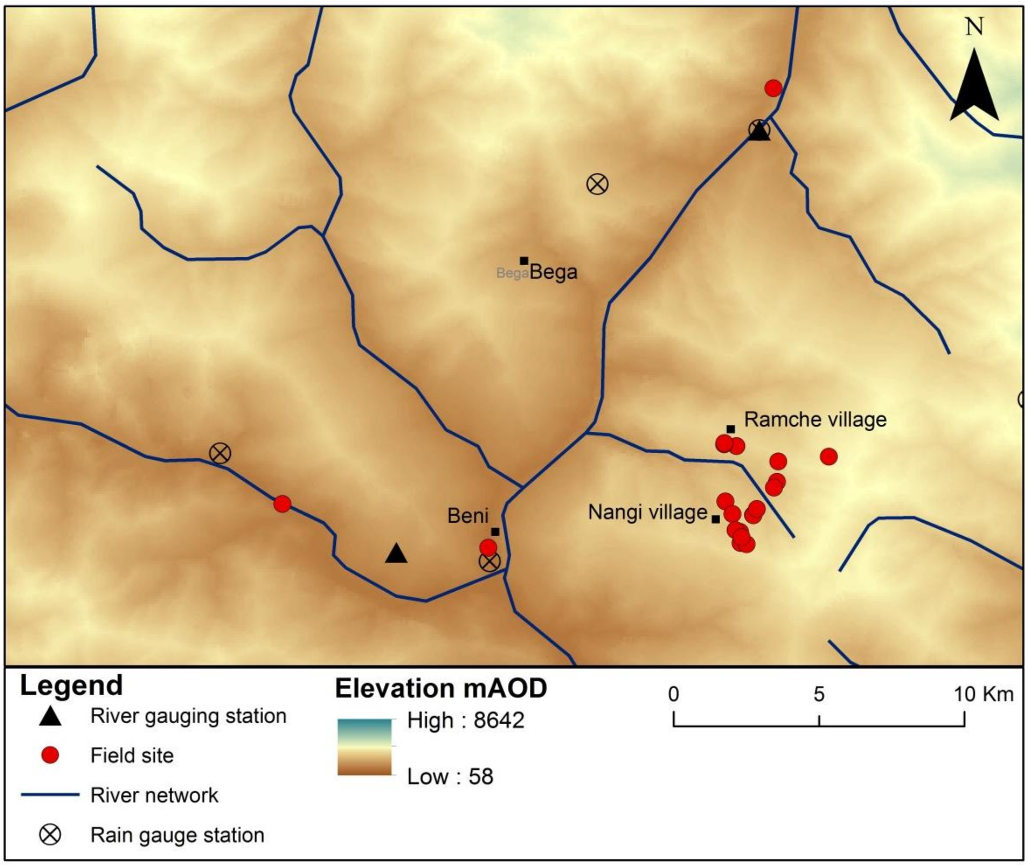



*Figure 12 - Ramche VDC, with field sampling locations, river gauging stations and rain gauges shown. Elevation data USGS (2004) Shuttle Radar Topography Mission.*

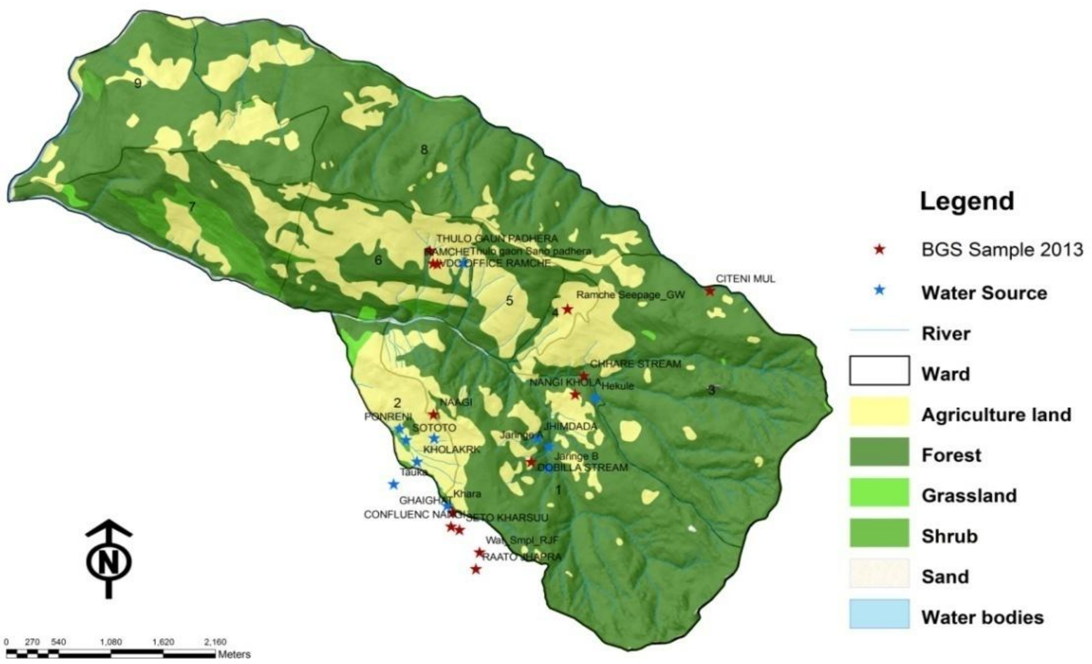



*Figure 13 - Ramche VDC with spring and stream water supply sources used for on-going discharge measurement shown.*

**Catchment water supply**

Aul khola and Basure khola are rivers located in the southern part of Ramche VDC; Pandoor river is located in the northern belt of the VDC. These rivers are perennial, though discharge is high during the rainy season and very low during the dry season. Aul, Basure and Pandoor are tributaries of the Kaligandaki river. The spring and stream water supply sources used for on-going discharge measurement are shown in Figure 14 and listed in Table 3.

In total 19 permanent water sources were recorded in the VDC. Of these, 14 were recorded in Nangi village (Wards 1, 2 and 5) and Ramche village (wards 3 and 4). Citeni spring in Ramche, Rato Jhapra spring and Seto Kharsu spring in Nangi are the major sources used for drinking, cooking and sanitation (Dixit et al. 2012). Nangi's drinking water supply system was completed in 2006 using Rato Jhapra (Dixit et al. 2012). Most of the water sources lie in the dense forest areas.

Seven springs (Table 4) were selected for sampling in Ramche VDC, these sites incorporate the major sources used for domestic water supply (Citeni, Rato Jhapra and Seto Kharsu) in addition to other water sources used in the villages. A description of these seven springs follows, including preliminary flows and water usage data collected through the community surveys.

| SN | Name | Location in VDC | Type |
|---|---|---|---|
| R.9 | Sanu Gaun Pandehra | Ramche village, Ramche | Perennial |
| R.11 | Citeni Mul | Ramche village, Ramche | Perennial |
| R.10 | Thulo Gaun Pandhera | Ramche village, Ramche | Perennial |
| N.1 | Tallo Pandhera | Nangi, Ramche | Perennial |
| N.2 | Seto Dhunga | Nangi, Ramche | Perennial |
| N.3 | Rato Jhapra | Nangi, Ramche | Perennial |
| N.4 | Seto Kharsu | Nangi, Ramche | Perennial |

*Table 4 - List of studied water sources in Ramche VDC*

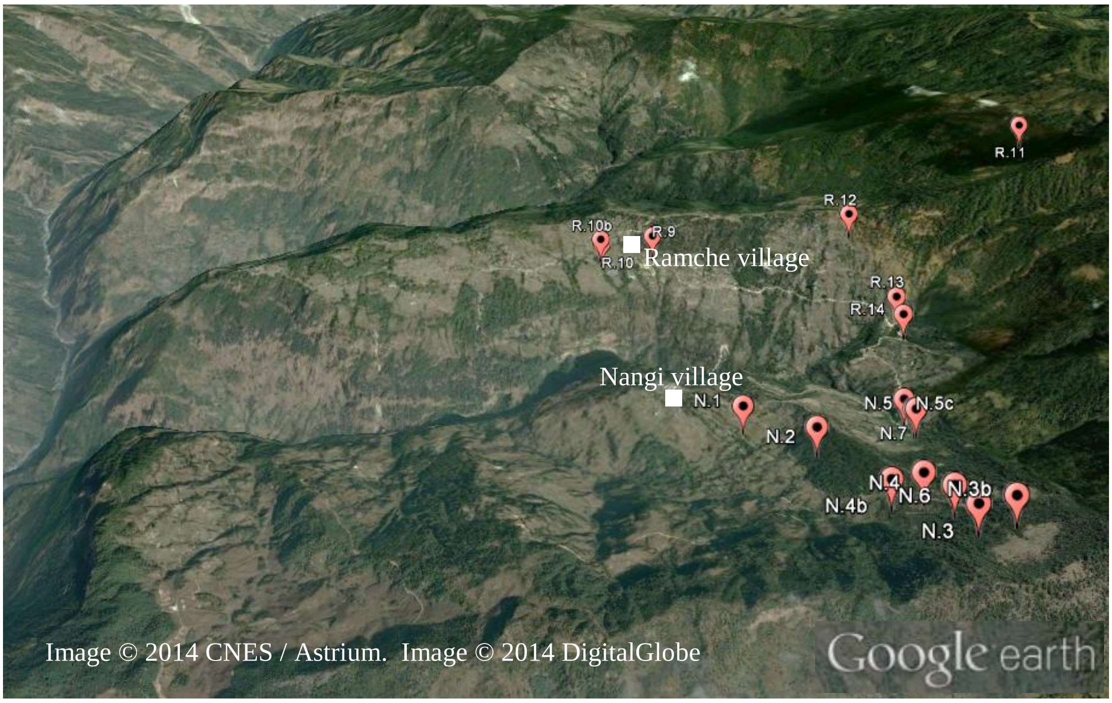



*Figure 14 - Ramche VDC with spring sources and sampling points indicated. Image © 2014 CNES / Astrium. Image © 2014 DigitalGlobe*

***Rato Jhapara (Nangi)***

This water source is located at 2559m asl. It is a perennial spring source in Nangi located on black clay and red mixed soil. The spring source faces the north-east slope. The upper part of the source is covered by rhododendron and mixed needle type of forest at the lower part. The spring source is located at an altitude of 2700m asl. Geographically the area is located at the eastern part of Ramche VDC. This source supplies drinking water to 36 households and a school, hostel and community lodge. The water is used primarily for domestic, livestock and irrigation purposes and additionally used to support a paper-making and jam-making business. Locals report that water usage over the last few years has remained the same. The flow is insufficient during the dry season. Spring flow in the post-monsoon season (Sept-13) was measured at 4.4 litres per second (l/s) using a bucket gauge; by pre-monsoon season (April-14) the flow had reduced to approximately 0.5-1 l/s.

***Seto Khasru (Nangi)***

This spring source is located at 2386m asl. It is another perennial spring source in Nangi located on the black clay and red mixed gravel soil. The upper part of the catchment is covered by mixed forest and the spring source is located at an altitude of 2600m asl facing the northern slope. Slopes are very gentle at the base of hill due to the presence of terrace farming. The source is used by 104 families for domestic, food and drink and livestock purposes. A small quantity of water is used for irrigation during the winter. Flow is minimal during the dry season. Spring flow in the post-monsoon season (Sept-13) was measured at 1 l/s using a bucket gauge. Flows in the pre-monsoon season (April-14) had reduced to <0.2 l/s.

***Seto Dhunga (Nangi)***

This source is located near Nangi village. It is also a perennial spring source located on the black clay and red mixed gravel soil. Needle type mix forest is dominant followed by rhododendron forest. The spring source is used by 10 – 15 households use for domestic purposes. This water source is preferable to the nearby spring source (Citeni) as it is warmer in the winter and better for washing. Flow was estimated to be 0.2 l/s in the pre-monsoon season (April-14). The site was not visited in the post-monsoon season (Sept-13).

***Tallo Pandhera (Nangi)***

This spring source located near Nangi village is perennial. Located near the community lodge of Nangi village its catchment has mix type of forest at the upper part of the source. The source is used by one household for domestic use and within a fishery. Flow was estimated to be 1 l/s during the pre-monsoon season (April-14). During the monsoon season the ground around the spring becomes marshy.

***Citeni (Ramche)***

This water source is located at 2816m asl. The people of Ramche (125 households) and Kafaldanada village (>200 households) are dependent upon this source. The spring source faces south-east and the top slopes have snow cover for ~4 months of the year. The upper part of the source is covered by rhododendron and mixed forest. The head of the spring is located at an altitude of 3000m asl facing south-west slope. Geographically this area is located at the north-western part of Ramche VDC. Flow in the main channel downstream from the spring was estimated using a bucket gauge to be 4l/s in the post monsoon season, by the pre-monsoon season flows had reduced to <0.5 l/s. Approx. 30 new taps supplied by this spring source were due to be constructed in 2014.

***Thulo Gaun Pandhera (Ramche)***

This spring source is located at 2370m asl. It is a perennial spring source for Ramche village located on the black mixed gravel soil. This serves as the main spring source for Ramche village.

The spring source faces the north-east slope. The upper part of the source is covered by *schima-castanopsis* and rhododendron mixed forest with settlements in the lower part. The source supplies approximately 20-30 households. One household uses the water supply for irrigation in the pre-monsoon season. In the winter months the overflow from the spring dries and the main tapped supply is reduced to 50%. There are no reported water scarcity issues even in the dry season. The spring source is reported to respond quickly to rainfall with flows increasing a day after the rainfall event.

***Sanu Gaun Pandhera (Ramche)***

This source is located within the Ramche village at an elevation of 2360m asl. Approximately 5-10 households use this but it is not considered as a major source, though it is perennial. It is a preferred spring source for washing in the winter as the water is warmer than other sources. The upper part of the source is covered by *schima-castanopsis* and rhododendron mixed forest and settlement at the lower part.

## 2.4 MADANPOKHARA, PALPA

### Location

Madanpokhara VDC is one of 65 VDCs in Palpa District (Figure 15). The Kaligandaki, Tinau, Ridi, Nisdi and Purwa are the major rivers in the district while the Satyawati, Pravash Lake and Sita Kunda form the main surface water features. The VDC is located at an altitude of 560-1240 m asl with a total area of approximately 1800 ha almost 40% of which lies below 1000 m asl. The landscape consists primarily of Middle Mountain, Churia foothills and flood plain. Agricultural land is situated along Mandi phant valley and is surrounded by the Mahabharat hills in the north and Siwalik Hills in the south (Moench, et al., 1999). Tansen Municipality is located north of Madanpokhara.

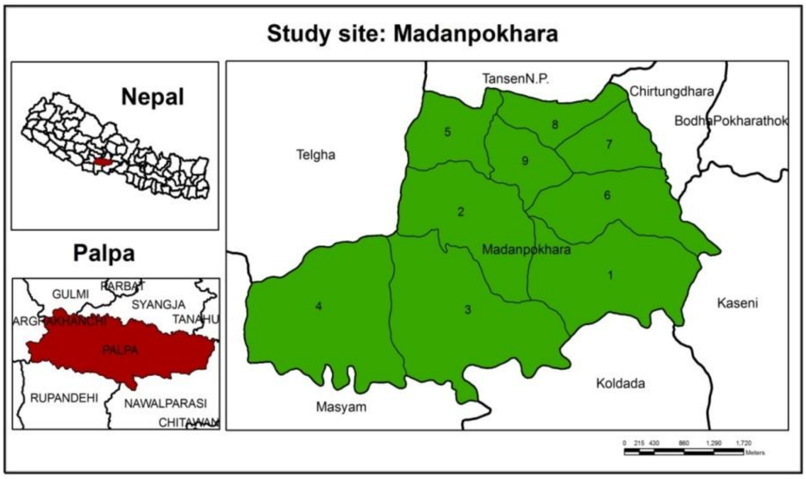



*Figure 15 - Location of Madanpokhara VDC and wards*

### Population and Literary

Madan Pokhara VDC has a population of 6,281 with 1,541 households (CBS, 2011). The VDC is inhabited by *Brahmins*, *Magar* and *Newar* castes, and members of the dalit community. Hinduism is the major religion in the VDC. The latest progress report of the VDC indicates that people are 100% literate. Commercial vegetable farming is the main source of employment in Madanpokhara VDC, though people are also engaged in civil services.

### Land use

Madanpokhara covers an area of approximately 1800 ha with most of the land used for agriculture (~80%). The remaining land is predominantly set aside for community forest with 13 community forest user groups in the VDC. Resources from the forest serve approximately 1,200 households of the VDC. The details of other forms of land use in the VDC and individual wards are listed in the Table 5.

| Ward | Agriculture (ha) | Forest (ha) | Shrub (ha) | Barren (ha) | Water bodies (ha) | Total(ha) |
|---|---|---|---|---|---|---|
| 1 | 114.19 | 25.34 | 1.98 | 0.34 | 1.77 | 143.62 |
| 2 | 107.98 | 32.80 | 8.84 | 0.20 | 0.00 | 149.83 |
| 3 | 38.34 | 87.54 | 10.50 | 0.00 | 3.46 | 139.84 |
| 4 | 53.42 | 116.99 | 0.24 | 0.52 | 1.50 | 172.66 |
| 5 | 376.68 | 10.61 | 0.00 | 0.00 | 0.00 | 387.29 |
| 6 | 191.14 | 8.09 | 0.58 | 0.00 | 2.26 | 202.07 |
| 7 | 254.05 | 4.15 | 0.58 | 0.00 | 0.00 | 258.79 |
| 8 | 254.05 | 8.17 | 0.00 | 0.00 | 0.00 | 262.22 |
| 9 | 84.31 | 7.26 | 0.00 | 0.00 | 0.00 | 91.57 |
| Total | **1474.16** | **300.95** | **22.73** | **1.06** | **8.99** | **1807.89** |

*Table 5 - Land Use within Madanpokhara VDC. (Source: Values derived from DOS, 1993)*

### Climate

Palpa district has a tropical to sub-tropical climate meaning Madanpokhara VDC experiences hot summers and warm winters. The mean maximum temperature of the district is 22.8°C and mean minimum is 13.4°C. There are two rain stations in the district provided by the Department of Hydrology and Meteorology, Government of Nepal which record an average annual rainfall of 1588 mm and daily maximum of 844 mm (Figure 16).

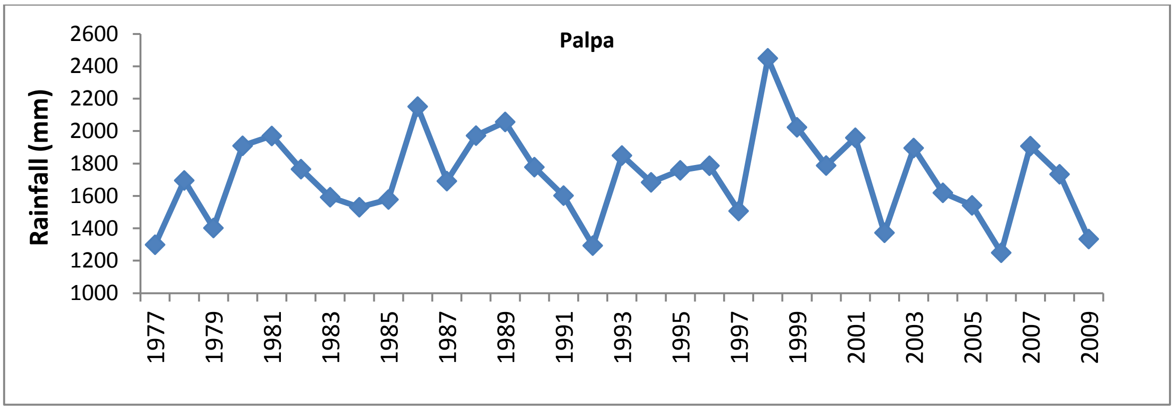



*Figure 16- Mean annual rainfall of Palpa district. Rainfall data from Department of Hydrology and Meteorology, Government of Nepal, gauging stations 726, 702.*

### Economy and Livelihood

Most people in Madanpokhara are employed in the agricultural sector though the business and service sectors offer an additional source of income. While some wards use sprinkler irrigation systems, all wards within the VDC lack formal canal irrigation facilities, as a result people practice rainwater harvesting and collecting it in ponds to support irrigation during dry periods, especially for vegetable farming. The cereal crop (especially paddy, wheat and maize) production is mostly dependent on a rain-fed system though rainfall is not sufficient to meet the water demand. Over the last 5 – 10 years groundwater resources, through the installation of shallow tubewells, have been exploited in some wards to support water demand for irrigation. Madanpokhara is a major supplier of vegetables to markets in Butwal.

### Nature of catchment and water source under study

In Madanpokhara VDC, the main catchment comprises the Tinau river in the eastern and southern part, with surface water flows to the Hulandi river in the western part of the VDC. The Tinau river originates from the Mahabharat range whereas the Hulandi river originates from the Siwalik range.

Details of the water sources investigated as part of this study are presented in Table 6 (Springs and streams) and Table 7 (Shallow tubewells) and shown in Figures 17-19.

The Andheri spring is a drinking water source for people of ward 1 and 2, the system was developed in 2007 (Dixit et al., 2012). People also use groundwater for drinking and irrigation needs. More than 10 water sources in the VDC have dried totally and seasonal drying of springs has also been reported (Dixit and Khadka 2013).

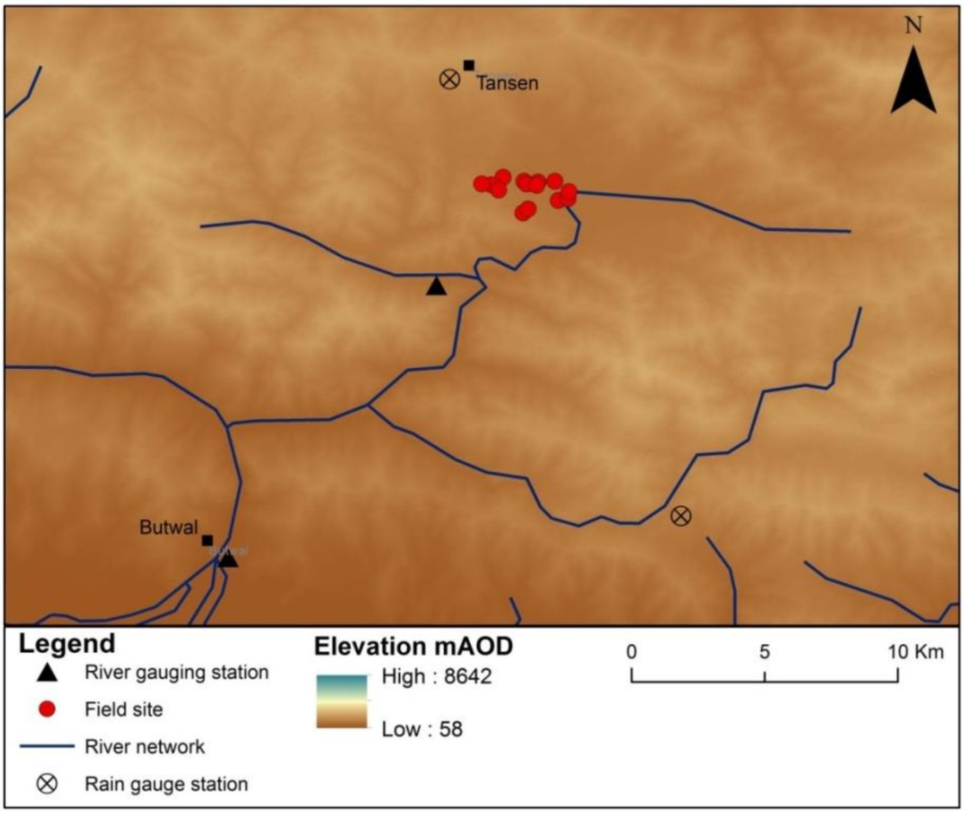



*Figure 17 Madanpokhara VDC, with field sampling locations, river gauging stations and rain gauges shown. Elevation data USGS (2004) Shuttle Radar Topography Mission.*


*Figure 18 - Location of the spring sources and sampling points in Madanpokhara. Image © 2014 CNES / Astrium*

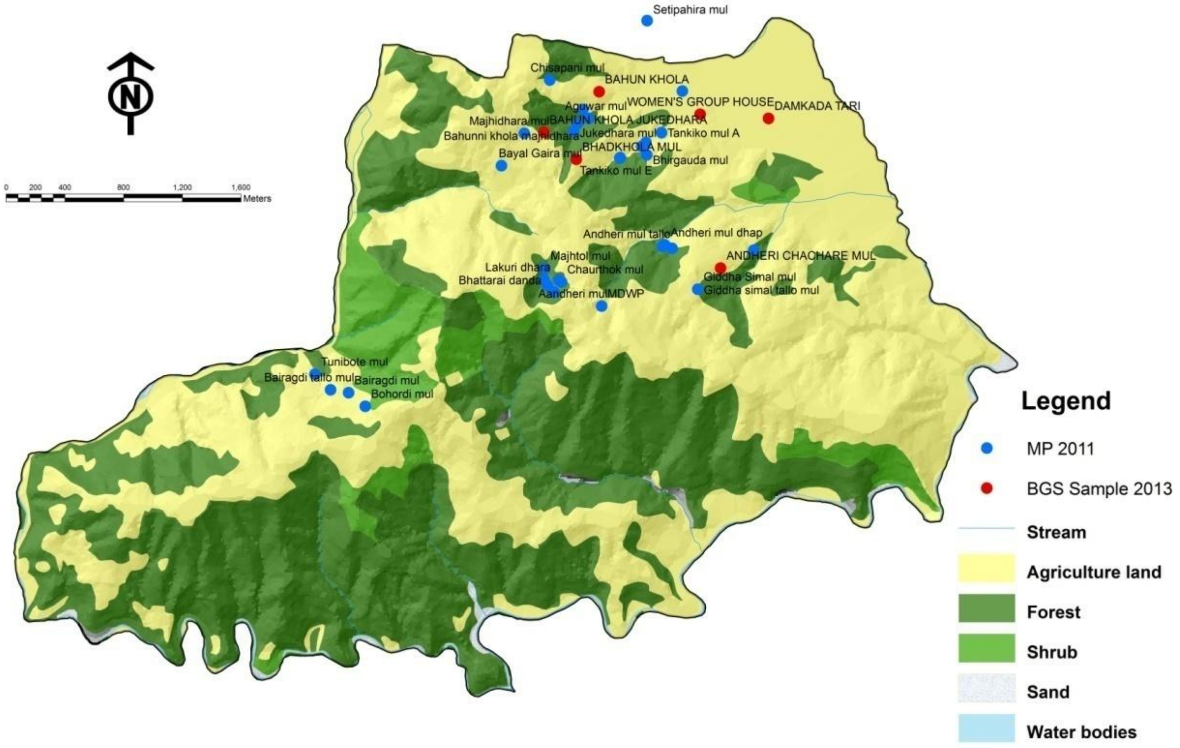



*Figure 19 - Location of studied sources at Madanpokahra*

| SN | Name of source | Location in VDC | Type |
|---|---|---|---|
| New | Nayapati | Madanpokhara-5, Nayapati | Perennial |
| MP.19 | Bahun Khola | Madanpokhara-8 | Perennial |
| MP.29 | Baad Khola | Madanpokahar-8 | Perennial |
| MP.31 | Andheri Charchare | Madanpokahara-6 | Perennial |
| MP.30 | Source near vulture conservation centre | Madanpokahara-6 | Perennial |
| MP.24 | Artesian tube well | Madanpokahara-6 | Perennial |
| MP.20 | Community tube well | Madanpokahara-7 | Perennial |

*Table 6 – Spring and stream sampling sites in Madanpokhara*

**Natyapati spring source**

This source is located at the Madanpokhara ward 5. Though perennial, spring discharge is very low during the winter and dry seasons. Approximately 10-15 households are using this source for domestic purposes. This site has been newly added to our monitoring programme and flow data for the spring is currently unavailable. This site was not visited during the post-monsoon and pre-monsoon field visits.

**Bahun Khola**

This stream source is one of the main water sources, supporting approximately 10 households. The land that surrounds this source is agricultural, predominantly for growing vegetables. The stream completely dries in the dry season, as any available water is collected for domestic water supply purposes. Outside of the dry season a small amount of stream flows occurs. A storage tank has been constructed close to the river which local farmers use for irrigation. People report that the tanks have water stored all year round. A pipe connected from the stream fills the tank. Flow was estimated to be approximately 5 l/s in the post-monsoon season (Sept-13), reducing to approximately 0.1 l/s in the pre-monsoon season (April-14). There is insufficient water for irrigation during the dry season, in which case they re-use domestic water. Water usage is reported to have been fairly steady over the last 5 years but an increasing population has led to increased water use.

**Baad Khola**

Groundwater seepages and springs serve as the main water supply for this source. The source is also fed by surface flows upstream with a series of narrow black alcathene pipes used to transport water down to the village. Three households and one hotel (wards 7 and 8) use the source for domestic purposes. In addition a small amount of water is used for irrigation (< 1 hectare). Flow in the stream downstream of the spring source was estimated to be 10 l/s during the post-monsoon season (Sept-13).

**Andheri Charchare**

The source is mainly used for meeting domestic needs and irrigation. During the dry season the local school in ward 6 uses this source to meet drinking water needs. Previously the flow was very low in the dry season but in recent years the flow in the dry season has increased. Locals think there has been an increase in flow because land near to this source has been afforested. Even though flow has increased it is still low during the dry season.

**Source near vulture conservation centre**

This source is located in ward 7, lies in the forest area and is used all year round. The amount of water used by individuals has remained fairly steady over the last 5-10 years or so but more people are using the source, hence there is greater demand for water from this source. At present 10-15 households are using the supply mainly for domestic use but also a small amount for irrigation.

**Shallow tube wells**

A large number of shallow tube wells have been installed in the last 5-10 years at the base of the slopes, within the flood plains and along rice fields of ward 6. These tubewells have been hand dug and tend to 60 – 80ft deep. The deepest tubewell is reported to be 125ft deep. Many tubewells have electric pump installed, shallower tubewells (<35ft deep) have hand pump. Some 10 or so tubewells are reported to have problems with high iron - evidence of high iron was observed at three tubewells during the field visits. The tube-wells provide a year-round water supply. Some of the tubewells towards the centre of the floodplain are reported to be artesian during the monsoon season. One tubewell (MP.24) was found to be artesian in the pre-monsoon season (April-14) and is likely to be artesian all year round. The floodplain in which the tubewells have been dug floods to a depth of one metre during the monsoon but typically only remains in flood for one day. Table 7 provides details of the tubewells sampled during the field visits.

| Tubewell | Depth | Installed | Use | Comments |
|---|---|---|---|---|
| MP.20 | 75ft | Unknown | 15 households for domestic purposes plus approx. 200l/day for irrigation. | Tubewell has never gone dry and is used all year round. |
| MP.21 | 60ft | 2010 | One household uses the tubewell for domestic use and irrigation. | The tubewell is artesian during the monsoon season. |
| MP.22 | 65ft | 2009 | One household uses the tubewell for irrigation all year round other than during the monsoon. | Suggestion of high iron content and an odour when drinking.<br>The tubewell is artesian during the monsoon season. |
| MP.23 | 80ft | Unknown | Used by 7 households for irrigation. | The tubewell was paid for by the government and installed with an electric 4 inch pump.<br>Iron odour. |
| MP.24 | Unknown | Unknown | Unknown | Artesian tubewell overflowing at a rate of 0.12 l/s during the pre-monsoon season (April-14). The lack of hand pump suggests it may be permanently artesian.<br>Iron staining but no odour. |
| MP.25 | 80ft | 2011 | One household for irrigation in the dry season. | An alternative source is used for drinking due to the high iron content.<br>Electric pump installed.<br>Rest water level (April-14) 1.2 m below ground. |
| MP.26 | 75ft | 2010 | One household for irrigation (0.6 hectares) except during monsoon. | Electric pump installed.<br>Another tubewell just uphill was dry when dug. |
| MP.27 | 42ft | 2004 | 6 households use for domestic and for irrigation except during monsoon. | Electric pump installed. |

*Table 7 - Description of the tubewells sampled in Madanpokhara VDC.*

# 3 Field Activities

An intensive programme of fieldwork, comprising hydrological and hydro-chemical monitoring and catchment and community surveys was undertaken during the post-monsoon season (16th – 26th September 2013) and pre-monsoon season (23rd April – 7th May 2014) in order to characterise the hydrogeological setting of catchments in the Middle Hills and to evaluate water resources and water usage. In addition, longer-term hydrological monitoring and water usage surveys were undertaken in the interval between the two field visits (Sept – April 2014) with a limited amount of monitoring continuing post-April 2014. Full details of the work undertaken and the field investigations employed are outlined below. The locations of sampling sites and details of the samples collected and site monitoring are provided in Appendix 1.

The results from the fieldwork should be viewed in the context of the antecedent weather conditions. In the absence of formal hydrometric data for our study catchments the following anecdotal antecedent weather conditions are provided. The first field visit in September 2013 was planned to capture the hydrological setting during the post-monsoon season. The monsoon season preceding the September field visit was described by locals in both Madanpokhara and Ramche/Nangi as being a particularly strong monsoon with more rain than normal. The second field visit in April and May was intended to capture the pre-monsoon hydrological regime, i.e. when groundwater resources are expected to be at their lowest. However residents in Ramche/Nangi noted that there had been rain and snowfall during the winter months of January and February, which was considered to be very unusual and more rain than normal had been received during the pre-monsoon months of March and April. Heavy afternoon rain showers were experienced on the first two days of field work in Nangi (25th and 26th April) however the rainfall did not result in discernible run-off due to large soil moisture deficits. Residents in Madanpokhara remarked that there had been no rain during the winter and pre-monsoon season prior to our visit and results are therefore expected to be reflective of a low groundwater resource situation.

## 3.1 CHARACTERISATION OF GROUNDWATER RESOURCES AND WATER USAGE

Water resources in the Middle Hills are under stress due to climate variability and changing land use practice such as deforestation, haphazard construction of roads and urbanization. Climatic variability and changes in precipitation, soil moisture and surface water, affects groundwater resources and spring flows and places increased stresses on local water management institutions. Other factors such as change in demand due to emerging aspiration for higher level of services, and deterioration of water quality will generate considerable stress on groundwater. As a result the temporal and spatial characteristics of groundwater are changing. The major issues in groundwater management in mid-hills of Nepal are considered to be:

- Loss of vegetation cover and forest
- Soil erosion and land degradation
- Land abandonment/encroachment and accelerated runoff
- Spatial and temporal variability in rainfall and availability of water - “too-little-and too-much water syndrome”
- Deteriorated water quality and health problems
- Glacier retreat and its impact on downstream rivers
- Non-availability of meteorological data
- Water induced hazards
- Dying wisdom of indigenous methods of coping up water scarcity and hazards

Assessment of impacts of environmental change on groundwater in Nepal's Middle Hills has not received adequate attention. To overcome this limitation, two catchments in Nepal's Middle Hills; Madanpokhara VDC and Ramche VDC as described in section 2 are being monitored throughout a hydrological year to investigate the availability and use of groundwater.

**Field observation:** The visit to Madanpokhara and Ramche VDCs aimed to understand the status of water sources and uses. The local communities were consulted to identify the type of water sources and locate them using Global Positioning Systems (GPS). Information such as vegetation, land types (agricultural/ barren land) and pollution status were also noted. Monthly water usage surveys were also undertaken January – March 2014 at four water supplies, two hand pumps in Madanpokhara and two spring sources in Ramche.

**Focus Group Discussion:** A detailed checklist was prepared and was used in the focus group discussion to solicit information related to past and present flow from sources, water supply management, disputes, scarcity issues and pollution. This interaction helped understand local perception of climate change and other water-related issues. The participants were the VDC secretary, school teachers, former chairperson of the VDC, and local farmers.

**Observations:**

*Madanpokhara:* In Madanpokhara, villagers use stream and spring sources in different wards for drinking purpose. Among them, the highest number of sources is in ward six. Drinking water is supplied via concrete tanks and alcathene pipes in ward one and four (Figure 20). In the VDC, 16 water sources are reported to have dried up which the local community attribute to a change in rainfall patterns, mismanagement and landscape changes. For meeting drinking needs in ward one and four, water is lifted by pump from lower elevations. In ward six, seven and eight, the majority of the households use spring water from a gravity-fed piped water system and groundwater abstracted from shallow tubewells. CBS (2011) indicates that 65% of households within the VDC use tap and piped water, 12% use tube well and rest use spouts. The water available for irrigation is not sufficient for cereal crops, especially for paddy and wheat so there is a heavy reliance on rainfall. For irrigation, four canals have been constructed-*Khauruha* canal in ward six and eight; *Adherai Argaule* canal in ward seven; *Jaljale* canal in ward seven and *Budi Tinau* canal in ward six. People of Madanpokara also use the Tinau River for irrigation, which originates from the Mahabharat range and flows through Mandi Phant and discharges to the Terai at Butwal.

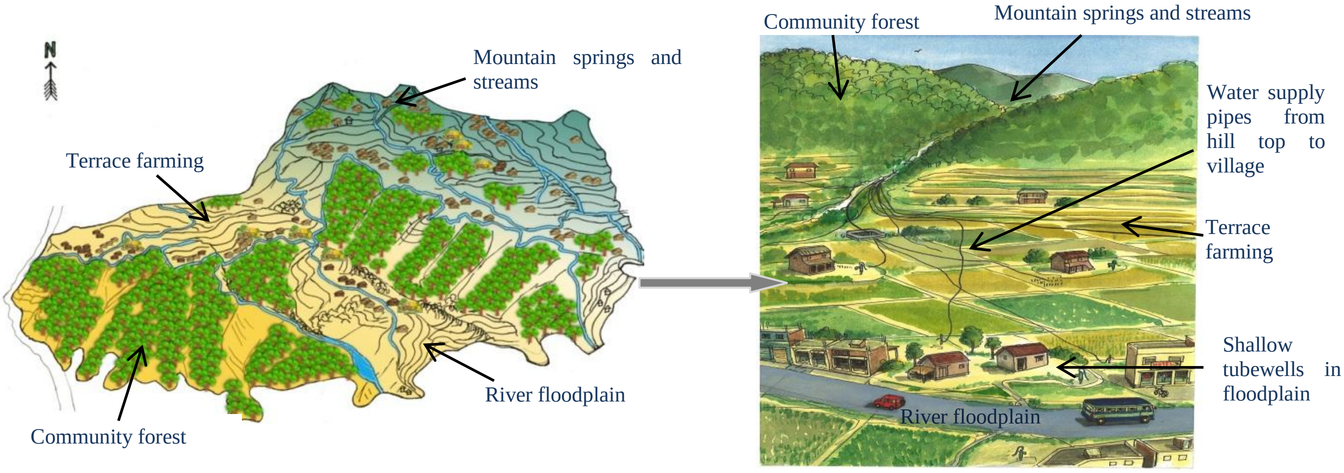



*Figure 20 - Illustrations of Madanpokhara catchment and drinking water practices, ©ISET-Nepal 2015.*

In most settlements, households use ponds lined with plastic (ultraviolet proof) and *ghaito* (jars) to harvest and store rain. The water stored is used for irrigated vegetable farming. Rain is collected in open ponds, lined with plastic to be used in the dry season (March-May). The production of vegetables has benefited farmers and many community-based user groups are involved in distribution and other aspects of vegetable farming.

*Ramche*: In Ramche VDC, springs are used for drinking supplied through pipes to households (Figure 21). On average, about 70% of households in the VDC have access to piped water supply for drinking. The VDC has no irrigation system, primarily because there are fewer terraces. Though traditional irrigation canals cannot be built, drips and sprinklers can support off-season cultivation.

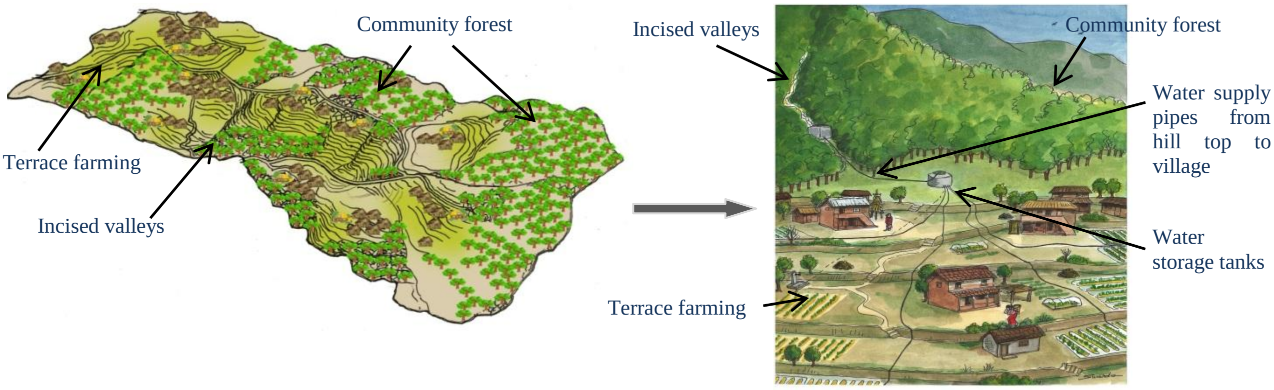



*Figure 21 – Illustrations of Ramche catchment and status of water use, ©ISET-Nepal 2015.*

## 3.2 DYNAMIC GROUNDWATER SYSTEM

### 3.2.1 Spring flow and temperature

*Figure 22 - Local community helper measures spring flow using a bucket gauge © NERC 2014*

As part of this study monitoring of spring flow was undertaken at 3 spring sources in Madan Pohkara (Baun Khola; Badkhola; Andheri Chhharchare), 2 spring sources in Nangi (Rato Jhapra; Seto Kharsu) and 2 spring sources in Ramche (Thulo Mul; Citeni Mul). Flow was being measured by local members of the community using the bucket gauge technique, where the time taken for the spring to fill a bucket of known volume (8 litres) is recorded. Where the spring water is piped from the source, the spring flow was measured from the pipe. Where the spring is not piped directly for supply, spring flow was measured at a suitable point downstream where spring flow forms a discrete flow channel that can be collected by a bucket. With both techniques there is the possibility that small volumes of spring flow were not captured by the bucket. The spring flow measurements may therefore be an underestimate of the total spring flow, this is most likely to be the case during monsoon and post-monsoon season when spring flow is high and excess spring flow not used for water supply over-flows into adjacent streams at some sites. The temperature of the spring water was measured using a glass-mercury thermometer. Spring flow was measured twice a day (am and pm) at these sites from 2nd July 2013 – 15th Nov 2013 and weekly from the 15th Nov 2013 onwards. Arrangements have been made by ISET-Nepal to continue the monitoring of spring flow and temperature, by the local community members, on a weekly basis at these sites. In addition to the spring flow measurements, flow emanating from an artesian well (naturally over-flowing well) in the Madanpokhara catchment will also be monitored using a bucket gauge.

### 3.2.2 Stream levels

*Figure 23 - Stilling well installed within the stream bed at Nangi to hang the stream level data recorder, ©NERC 2014*

In addition to the spring flow measurements water levels within three streams which are fed by the springs and which flow alongside the springs have been monitored using an automatic data level recorder. Two of the sites are located in Nangi (Rato Jhapra and Seto kharsu) and one site is located in Ramche (Citeni Mul). Water levels in the streams were recorded by the data logger at a 15-min time interval. A temporary stilling well made out of perforated plastic pipe (~2inch diameter) was installed into the stream bed at the side of the channel from which to hang the data logger and to protect it from strong currents and debris. The data loggers were installed in Sept 2013 and data from them downloaded in April

2014. The data loggers at Rato Jhapra, Nangi and Citeni Mul, Ramche were re-set in April 2014 for on-going monitoring. The data logger at Seto Kharsu, Nangi was removed in April 2014. The streams being monitored in Nangi and Ramche source some distance further upstream than the point at which they are being monitored. As such the stream levels being recorded will be representative of the hydrological regime higher up the catchment i.e. there may be additional springs, tributaries and snow melt contributing to the stream flow. Stream levels in Madanpokhara have not been monitored and no suitable shallow tubewells, unaffected by abstraction, were identified in the Madanpokhara catchment for long-term groundwater level monitoring. The stream level data are not presented within this report, further stream level data are being collected and will be subject to further processing and analysis.

### 3.2.3 Groundwater chemistry

Water samples for groundwater chemistry analysis (major and trace elements) were collected from 17 sites visited during the Sept-2013 field excursion and for 27 sites visited during the April/May-2014 field excursion. Groundwater chemistry samples were collected in order to assess the hydrogeological environment of the catchment rather than to assess the suitability of water resources for drinking water. However, concentrations of determinants in excess of the Nepal drinking water quality standards (DWQS) are highlighted where appropriate (Appendix 1). Bacterial analysis of the water samples was not undertaken.

Where samples were collected from tubewells every effort was made to purge the well three times the well volume prior to collecting the sample or to collect a sample from a recently pumped well. Where this was not possible this was indicated in the field notes. At each site, measurements were made of alkalinity (by titration against $H_2SO_4$), temperature, specific electrical conductance (SEC), pH, dissolved oxygen (DO) and redox potential (Eh). The latter four parameters were measured in an anaerobic flow cell to prevent contact with the atmosphere and parameters were monitored until stable readings were obtained. In a few cases, use of a flow cell was not possible and on-site parameters were measured rapidly in a bucket. In each case a note was made of the sampling conditions.

Samples for major and trace element analysis were collected in factory-new rinsed polyethylene bottles and filtered to <0.45 μm. Filtration was performed using a disposable filter and syringe. Samples for cations and trace element analysis during the Sept-2013 field excursion were acidified at the end of each day to 1% (v/v) using $HNO_3$ (nitric) acid. Since current aviation regulations prohibit the transportation of nitric acid on passenger aircraft nitric acid was locally-sourced from a Nepali chemist. However duplicate samples for cations and trace element analysis were collected and acidified to 1% (v/v) upon return to the UK in BGS laboratories using ARISTAR $HNO_3$. Laboratory results from samples collected in Sept-2013 indicated that the $HNO_3$ acid sourced in Nepal was contaminated with metals. Therefore samples collected during the April/May field excursion were acidified to 1% (v/v) upon return to the UK in BGS laboratories using ARISTAR $HNO_3$. Samples for non-puregable organic carbon (NPOC) analysis were filtered through a 0.45 μm silver impregnated filter and collected in glass vials pre-cleaned with chromic acid.

Analysis of major and trace cations, and Iodine was carried out by inductively-coupled plasma mass spectrometry (ICP-MS). Anions were determined by ion chromatography (IC) and alkalinity testing of each sample repeated in the laboratory was determined by potentiometric titration. Samples for NPOC were analysed using a Total Organic Carbon (TOC) analyser.

### 3.2.4 Stable isotopes

The stable isotopes of water ($\delta^{18}O$ and $\delta^{2}H$) can be used as a tracer of the origin of groundwater recharge since $\delta^{18}O$ and $\delta^{2}H$ ratios vary seasonally and with latitude, temperature and with altitude. Stable isotope samples were collected for the 17 sites visited during the Sept-2013 field excursion and for the 27 sites visited during the April/May-2014 field excursion. A rain sample was also collected for stable isotope testing during each field visit.

Three spring sources in Madanpokhara (Baun Khola, Badkhola and Andheri Chharchare), two springs sources in Ramche (Thulo Mul and Citeni Mul) and two spring sources in Nangi (Seto Jharsu and Rato Jhabra) have been selected for longer-term stable isotope sampling to access seasonal trends. Samples have been collected on a fortnightly basis from Oct 2013 to present. Due to the limited funds available for laboratory costs only monthly stable isotope samples for these seven springs, from Oct 2012 – Mar 2013, have been submitted to the laboratory for testing.

Samples for the determination of stable isotopes ($\delta^{18}O$ and $\delta^{2}H$) were collected unfiltered in factory-new rinsed polyethylene bottles.

### 3.2.5 Groundwater residence time indicators

Chlorofluorocarbons (CFC) and sulphur hexafluoride ($SF_6$) are anthropogenic environmental tracers occurring in the near-surface environment. The concentration of CFC and $SF_6$ in groundwater can be used to make inferences about the timescales of groundwater processes operating within the catchment. CFC and $SF_6$ are particularly useful for dating groundwater less than 100 years old since concentrations of CFC and $SF_6$ have been accumulating in the atmosphere since the late 1930s and early 1970s respectively and have a known groundwater solubility (Darling et al 2012).

Samples for CFC and $SF_6$ analysis were collected within a pre-rinsed glass bottle. It is essential that the sample is airtight and does not come into contact with the atmosphere. To achieve this, the water source is pumped (suction pipe or caravan pump) into the glass bottle which is placed within a bucket. The bucket is filled and overflows with the pumped water to completely submerge the glass bottle before the cap is secured to the bottle. The bottle cap is secured with electrical tape which is wrapped in a clockwise direction three times around the bottle neck.

Where samples were collected from tubewells every effort was made to purge the well of three times the well volume prior to collecting the sample or to collect a sample from a recently pumped well. Where this was not possible this was indicated in the field notes.

CFC and $SF_6$ samples were collected from seven spring sources during the Sept-2013 field excursion and from 11 springs, one hot-spring, one large diameter well and eight tubewells during the April/May field excursion.

### 3.2.6 Noble gases

The temperature of groundwater recharge can be determined from the concentrations of Argon, Krypton, Neon and Xenon noble gases in groundwater and therefore provides an indication of the contribution of snow and ice melt to groundwater recharge and the recharge season and elevations.

Samples for noble gas analysis were collected from seven spring sources during the Sept-2013 field excursion and from three springs, one hot-spring and one tubewell during the Apr/May field excursion. The sample is collected in copper tubing. It is essential that the noble gas sample is airtight and does not come into contact with the atmosphere. To achieve this, the water source is pumped (suction pipe or caravan pump) and connected via a length of hose to the copper pipe which is then clamped shut. Where samples were collected from tubewells every effort was made to purge the well of three times the well volume prior to collecting the sample or to collect a sample from a recently pumped well. Where this was not possible this was indicated in the field notes. The noble gas sample results were not available at the time of reporting.

# 4 Preliminary findings

## 4.1 WATER USAGE

Community surveys indicate that springs are the main source of water in Ramche VDC, while in Madanpokara, springs sources are supplemented by shallow tubewells installed over the last 5-10 yrs. The tubewells are used predominantly for irrigation while the springs in both districts are used for domestic purposes. Many of the springs are perennial but with significantly lower flows reported by communities in the dry season (pre-monsoon) and water scarcity issues occurring in some localities as a result, e.g. insufficient water for irrigation in parts of Madanpokhara. Small concrete water storage tanks constructed alongside the springs and streams are important for maintaining supplies during dry periods. In Ramche VDC surplus water from larger spring sources is diverted to augment water supplies for smaller settlements with less reliable springs. Both communities believe re-afforestation around springs has an important role in sustaining reliable flows and protecting water sources.

*Madanpokhara*

The residents of Madanpokhara have access to both piped spring water and groundwater sources and some also have access to an established rainwater harvesting system. The majority of households in Madanpokhara also have electricity, sanitation facilities, and communication systems. Today 78 % of villagers use drinking water piped to tap stands from springs. The VDC started using sprinklers for irrigation in the 1990s and rainwater harvesting and water-storing plastic ponds for irrigation have become common in recent years.

There are more than 250 small springs recorded in Madanpokhara VDC, though only ~50 of these are considered to be major sources for water supply purposes. In addition to the spring sources there are approximately 100 rainwater harvesting sites and 100 shallow tubewells installed in the last few years to support irrigation. The demand for water in Madanpokhara has increased as agriculture has grown and intensified. Community members in Madanpokhara stated that crop production has increased 10-fold in the last 10 years, and domestic use has also increased slightly. Individual water usage has not increased significantly but population has increased as they are attracted by the opportunity for commercial agriculture. Family sizes are also increasing. A shift in behaviour with people becoming more health conscious and with greater attention to cleanliness and sanitation may have led to an increase in water consumption.

There is anecdotal evidence of spring depletion and spring migration in Madanpokhara. After a decade of deforestation, 1962 to 1972, and anecdotal evidence of increased landslides and small spring sources drying up (Gyawali and Dixit, 1999), households turned the situation around by beginning to conserve local forests.

*Ramche*

As with Madanpokhara, Ramche VDC has a large number of springs but only 15-20 of these are considered to be major sources for water supply purposes. Over the last 30 years a series of concrete water storage tanks, filled by spring and stream water and served to communities via pipes and taps, have been installed in Myagdi district. This method of water supply system continues to be implemented today with a current government initiative, coordinated at district level, to install further water supplies using storage tanks filled by small mountain streams. These new supplies are being installed to improve reliability and formalise the water supply systems rather than to address water scarcity. The schemes allow for 35 l/day/household and are managed by a water user community group. Tubewells are not being considered for Myagdi as it would be difficult to mobilise a drilling rig in the steep slopes and because electricity to power pumps is intermittent. The population in Ramche VDC is fairly steady, though farming is declining due to a reduced labour force. There has also been a shift towards potato and maize crops as they require less water and are easier to sell to nearby towns. The main concerns in

Ramche VDC are declining spring discharge, increased pests, disease affecting the forest and water disputes, e.g. where not all wards are represented in the water user group.

***Water use:*** Two water sources from each catchment were monitored monthly for three months in Madanpokhara and for four months in Ramche to understand water consumption pattern in the VDCs. In Madanpokhara two hand-pumps from ward number from 5 and 7 were selected to monitor the water consumption (Table 8). Water use was slightly less in late winter (January) and gradually increased to the early summer season (March) due to increasing demand in drinking and irrigation.

*Chappani mul (Ward 5): Publicly owned hand-pump mostly used for sanitation. It is used by 10 households year round with an additional 5-10 households using it during the dry season. Average water consumption per household 107 – 215 l/day.*

| **Date** | **Water usage (litres) over 7 hours** | | | |
|---|---|---|---|---|
| | **Drinking** | **Sanitation** | **Livestock feeding** | **Total** |
| 4-Jan-14 | 400 | 1500 | 200 | 2100 |
| 1-Feb-14 | 420 | 1600 | 250 | 2270 |
| 1-Mar-14 | 450 | 1400 | 225 | 2075 |
| **Average** | 423 | 1500 | 225 | 2148 |

*Damkada pump (Ward 7): Privately owned hand-pump used for domestic purposes and for irrigation for vegetable farming. It is used by one household only. Average water consumption per household 2170 l/day.*

| **Date** | **Water usage (litres) over 7 hours** | | | | |
|---|---|---|---|---|---|
| | **Drinking** | **Sanitation** | **Livestock feeding** | **Irrigation** | **Total** |
| 11-Jan-14 | 25 | 250 | 25 | 1500 | 1800 |
| 8-Feb-14 | 25 | 250 | 25 | 2000 | 2300 |
| 8-Mar-14 | 35 | 250 | 25 | 2100 | 2410 |
| **Average** | 28 | 250 | 25 | 1867 | 2170 |

*Table 8 - Water consumption pattern at Chappani mul Hand-pump and Damkada Hand-pump, Madan Pokhara VDC.*

In Ramche, two spring water sources were selected to monitor water consumption. Table 9 depicts the pattern of water consumption. Generally water from the source is used for domestic purpose and livestock feeding. For irrigation, water use was less in winter season( December and January) and gradually started to increase in late winter (February) and summer season (March). The water demand is increasing for drinking, irrigation and livestock feeding.

*Seto Dhunga (Ward 2): Public spring source used by 6 households. Average water consumption per household 310 l/day.*

| **Date** | **Water usage (litres) over 7 hours** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Drinking** | **Cooking** | **Dish wash** | **Bathing** | **Washing cloths** | **Toilet and Sanitation** | **Livestock feeding** | **Others** | **Total** |
| 14-Dec-13 | 90 | 120 | 360 | 100 | 160 | 120 | 800 | 10 | 1760 |
| 11-Jan-14 | 90 | 120 | 360 | 100 | 160 | 120 | 900 | 10 | 1860 |
| 8-Feb-14 | 120 | 120 | 360 | 120 | 160 | 120 | 900 | 10 | 1910 |
| 8-Mar-14 | 120 | 120 | 360 | 120 | 160 | 120 | 900 | 10 | 1910 |
| **Average** | 105 | 120 | 360 | 110 | 160 | 120 | 875 | 10 | 1860 |

*Thulo Gaun Pandhera (Ward 4): Public spring source used by 3 households. Average water consumption per household 510 l/day.*

| **Date** | **Water usage (litres) over 7 hours** | | | | | |
|---|---|---|---|---|---|---|
| | **Drinking, Cooking and Dish wash** | **Bathing** | **Toilet and Sanitation** | **Livestock feeding** | **Irrigation** | **Total** |
| 14-Dec-13 | 160 | 150 | 160 | 212 | 800 | 1482 |
| 11-Jan-14 | 160 | 150 | 160 | 222 | 800 | 1492 |
| 8-Feb-14 | 160 | 125 | 160 | 172 | 800 | 1417 |
| 8-Mar-14 | 160 | 225 | 160 | 182 | 1000 | 1727 |
| **Average** | 160 | 162.5 | 160 | 197 | 850 | 1529.5 |

*Table 9 - Water consumption pattern at Seto Dhunga and Thulo Gaun Pandher, Ramche VDC.*

## 4.2 GROUNDWATER SYSTEMS IN THE MIDDLE HILLS

### 4.2.1 Data analysis

**Spring flow measurements**

Spring flow data for a full hydrological year (July 2013 – June 2014) has been collected for four water supply springs in the Madanpokhara VDC and four water supply springs in Ramche VDC. Spring flows in Madanpokhara are generally lower possibly reflective of lower annual average rainfall totals and a smaller catchment area above the spring discharge points. The springs in all districts show a decline in spring discharge from high spring discharge during the monsoon season, declining during the post-monsoon season through to low spring discharge during the winter and pre-monsoon season (Table 10, Figures 26, 27, 28). The timing of spring flow decline varies between the different districts with typical spring recession starting during August-September in Nangi and during November in Ramche and Madanpokhara. Springs in all districts have winter and pre-monsoon flows of less than 1l/s. The rise in spring flow at Andheri Chharchare during the pre-monsoon season (Figure 28) is due to the introduction of an additional water pipe to the spring source to maintain sufficient water supply for downstream residential properties. Spring flows during the monsoon season tend to exhibit greater variability, this is especially so at Citeni in Ramche and Rato Jhapra in Nangi.

Further analysis of the spring flows is planned when more flow data become available and a year's worth of stable isotope samples have been analysed.

| | **Average spring flow (Litres per second)** | | | |
|---|---|---|---|---|
| | Monsoon (July-Sept) | Post-monsoon (Oct-Nov) | Winter (Dec-Feb) | Pre-monsoon (March-June) |
| **Madanpokhara** | | | | |
| Baun Khola | 0.71 | 0.58 | 0.38 | 0.25 |
| Baad Khola | 0.29 | 0.27 | 0.24 | 0.05 |
| Andheri Chharchare | 0.26 | 0.27 | 0.08 | 0.05 |
| **Nangi** | | | | |
| Rato Jhapra | 4.69 | 2.24 | 0.56 | - |
| Seto Kharsu | 1.46 | 0.76 | 0.18 | - |
| **Ramche** | | | | |
| Thulo Mul | 0.43 | 0.27 | 0.17 | 0.14* |
| Citeni | 6.37 | 7 | 0.83 | 0.22* |

*Table 10 - Seasonal variation in measured (bucket gauge) spring flow at springs in Madanpokhara and Ramche VDCs. * Data for March and April only.*

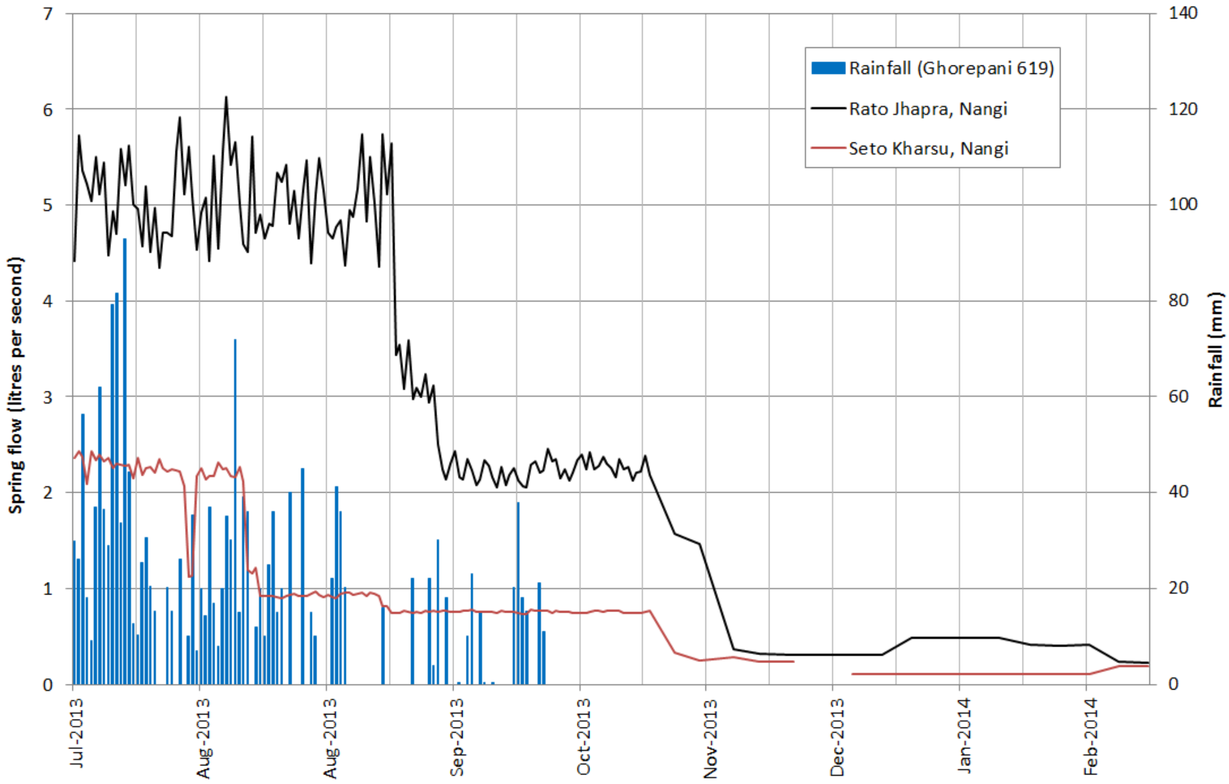



*Figure 24 - Spring flow measurements for the principal water supply springs within Nangi district. Rainfall data from Ghorepani rain gauge to end December 2013 shown.*

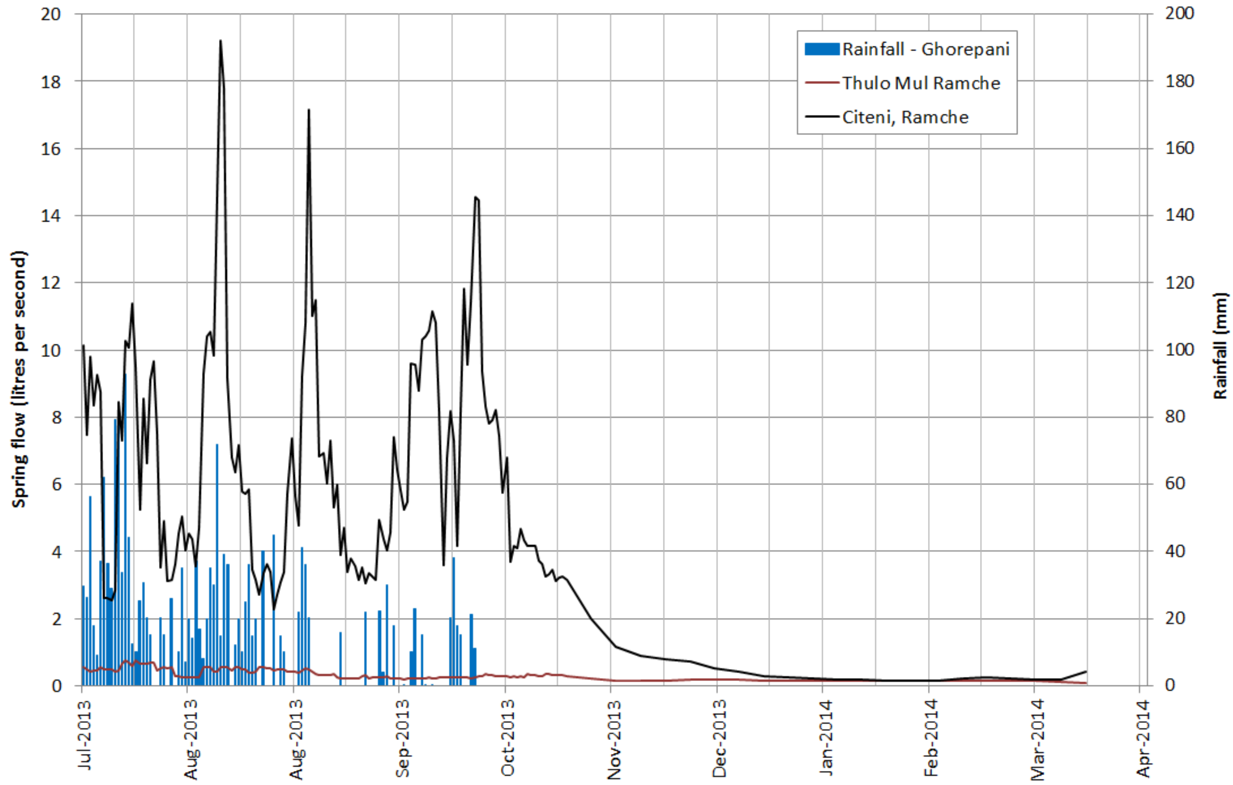



*Figure 25 – Spring flow measurements for the principal water supply springs within Ramche district. Rainfall data from Ghorepani rain gauge to end December 2013 shown.*

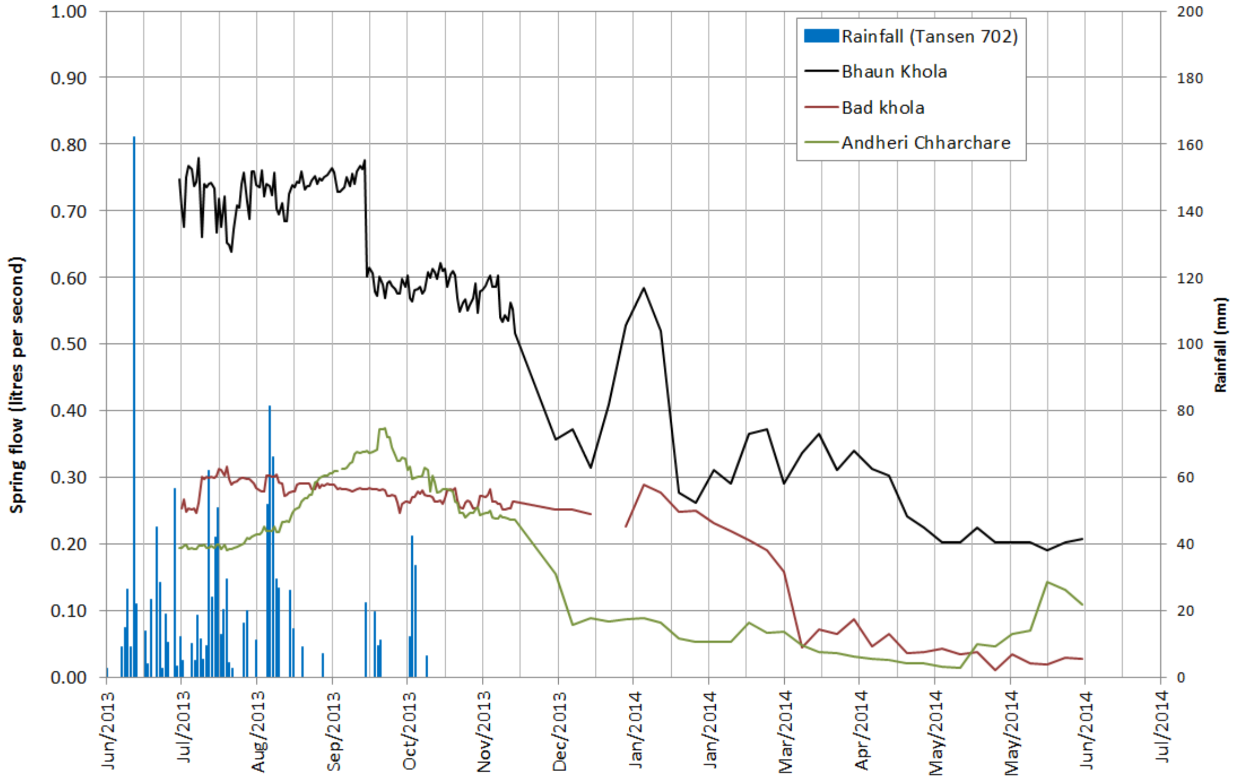



*Figure 26 - Spring flow measurements for principal water supply springs with Madanpokhara district. Rainfall data from Tansen rain gauge to end December 2013 shown.*

**Groundwater chemistry**

Major groundwater chemistry is shown in Figure 29. Groundwater sampled within Madanpokhara is dominated by the bicarbonate anion but a more complicated pattern emerges for the cations: springs are dominated by calcium and magnesium, consistent with a dolomitic geology; however hand pumps become increasingly dominated by sodium as samples are taken further into the floodplain, reflecting likely cation exchange. The groundwater chemistry of the handpumps in the floodplain also indicates reducing conditions with elevated iron and manganese concentrations and sulphate reduction. Comparatively high concentrations of arsenic and zinc are also detected in two of the handpumps drilled into the floodplain deposits. The groundwater chemistry of handpumps drilled at the margin of the floodplain at the base of foothills in Madanpokhara, is more akin to the chemistry of groundwater in an oxidised, unconfined aquifer setting with lower iron and manganese concentrations, and groundwater chemistry is generally similar to the spring water in the adjoining hills. Groundwater chemistry of springs in Nangi and Ramche is also dominated by bicarbonate, with no significant difference in chemistry between pre- and post-monsoon seasons. There is a suggestion that springs at lower elevations not located within the incised stream channels tend to have lower bicarbonate concentrations. In Ramche and Nangi, there is no dominant cation, with calcium, sodium and magnesium all generally present.

Only one groundwater chemistry sample was collected from the main river terrace deposits associated with the Kali Gandaki River at Beni. The chemistry results for this site show low dissolved oxygen concentrations perhaps due to a clay confining layer within the floodplain deposits. Despite the reducing conditions, iron and manganese concentration were not elevated. Comparatively high levels of Boron, Rubidium, Molybdenum, and Uranium, were detected which are indicative of a granitic geology within the catchment.

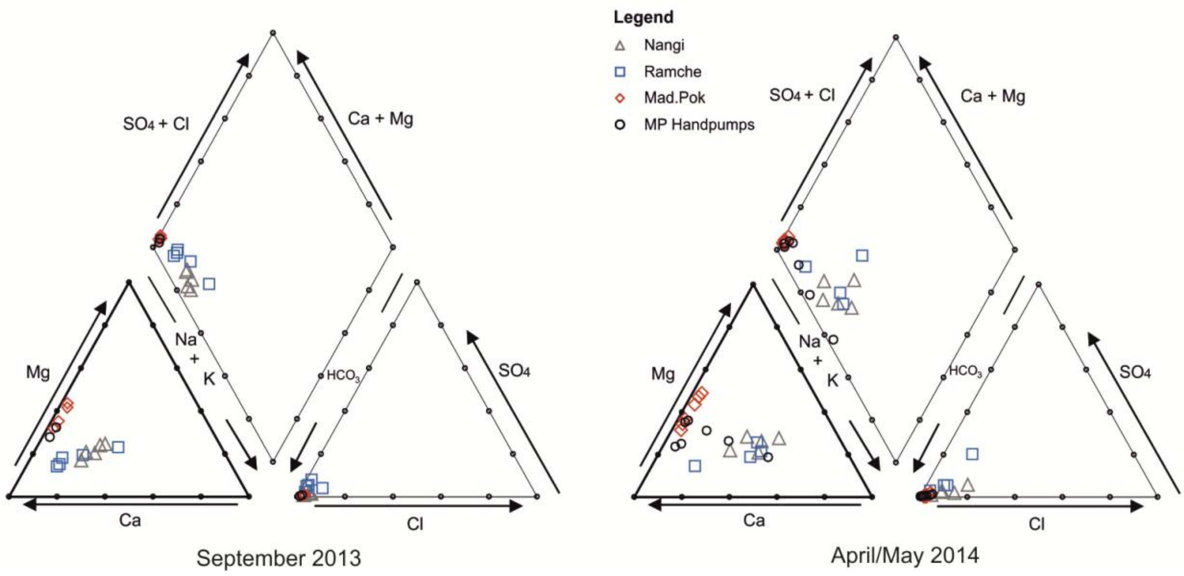



*Figure 27 - Piper diagram showing the major ion chemistry for all sites sampled in Madanpokhara, Nangi and Ramche during Sept-13 (post-monsoon) and April/May-14 (pre-monsoon).*

### Groundwater Age Indicators (CFC, $SF_6$)

Samples for CFC and $SF_6$ were taken for both the pre and post monsoon sampling rounds. CFC concentrations tended to be over modern for the spring samples. Given the high altitude location of many of these springs, and their location with community forests, it is unlikely that all the over modern water is from contamination. It is more likely that the increased concentrations are due to the low temperatures, snow melt or turbulent flow processes. The $SF_6$ data give more consistent results, and where the CFC data are from handpumps where the groundwater is not reducing, there is good agreement between the two. Therefore $SF_6$ data are taken to be representative of the mean residence time (MRT) of the groundwater.

Preliminary interpretation of the data indicate that springs in Nangi and Ramche had consistently young mean residence times within 10 – 20 years: older groundwater tended to be from discrete springs and younger groundwater from more diffuse channels.

In Madanpokhora an interesting pattern emerges from the springs in the hillslope to boreholes in the floodplain. Groundwater from springs again appeared to have a mean residence time of approximately 10 – 20 years. The mean residence time at the edge of the floodplain close to the hillslope was within a similar range, although slightly older. Within the middle of the floodplain however, mean residence time increased significantly and was > 50 years.

### Stable Isotopes

A trend of increasingly depleted $\delta^{18}O$ and $\delta^{2}H$ values with elevation is observed in the data (Figure 30), with sites in the Ramche and Nangi catchments, at elevations of 2200 – 2800 m asl, having more depleted O and H stable isotope values than Madanpokhara which occupies elevations of 500-700 m asl. This is consistent with local source of recharge to the springs.

There are also differences in the stable isotope values between post-monsoon (Sept-13) and pre-monsoon (Apr-14) seasons for many of the sites within the Ramche and Nangi catchment, though the effect is most pronounced for sites in the higher catchment of Ramche (Figure 30). For the post monsoon samples, stable isotopes are more depleted, inferring a more elevated source for water sampled from the springs. This could be explained by springs having a significant surface water contribution in the monsoon season, which reduces throughout the winter as flow reduces and is sourced mainly from local groundwater. There are two exceptions: Thulo Mul (Ramche) and Rato Jhapra (Nangi) show little difference in stable isotope composition between the two seasons suggesting a more localised or more seasonally consistent groundwater capture zone.

Stable isotope results for the handpumps located in the floodplain deposits in Madanpokhara are different to the spring sources of the same catchment, with groundwater sampled from the handpumps having a more localised source than the springs. This may suggest that groundwater within the floodplain is distinct from groundwater within the weathered zone of the hillslopes. Handpumps located at the margin of the floodplain have stable isotope compositions more akin to the springs in Madanpokhara.

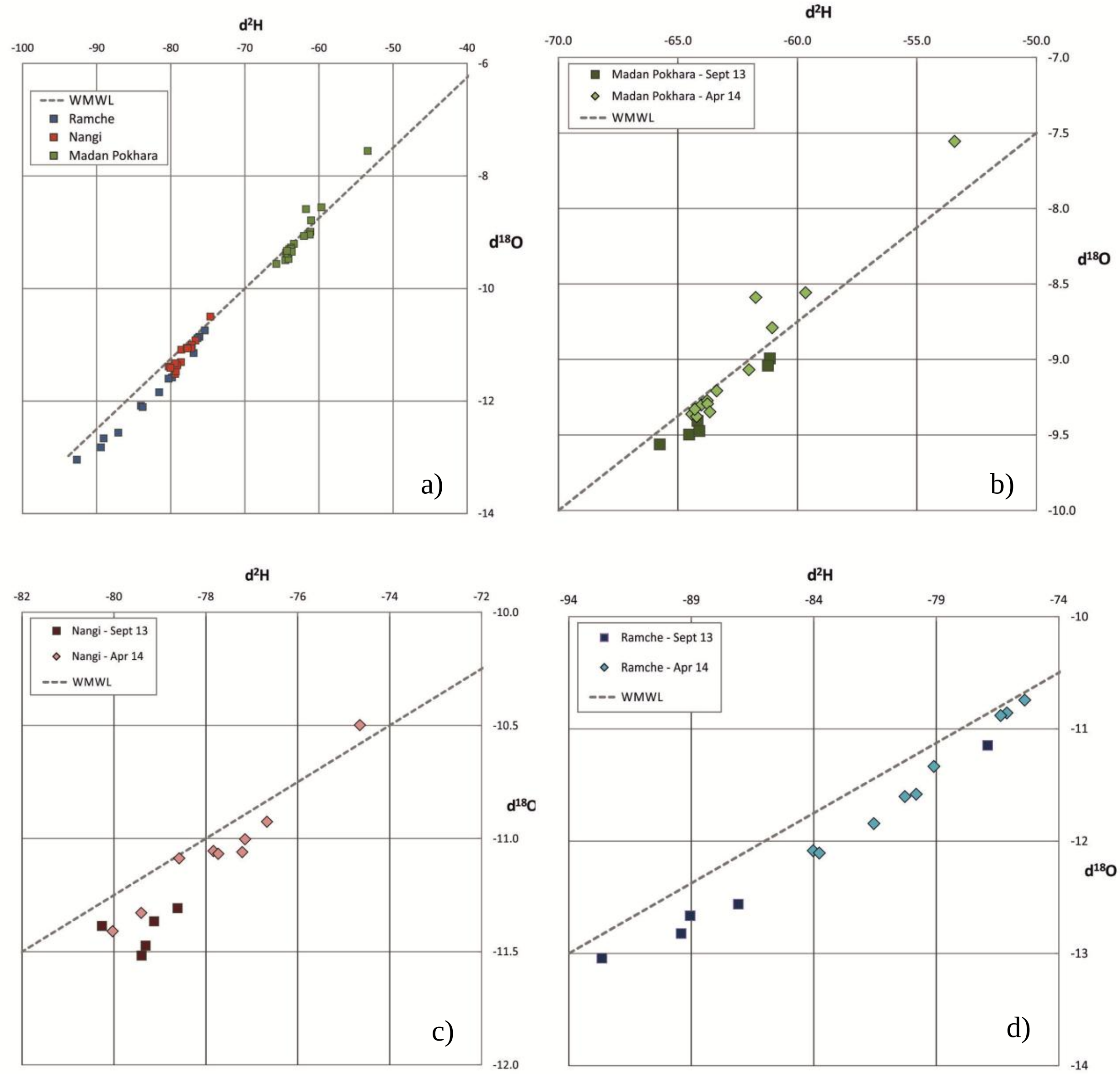
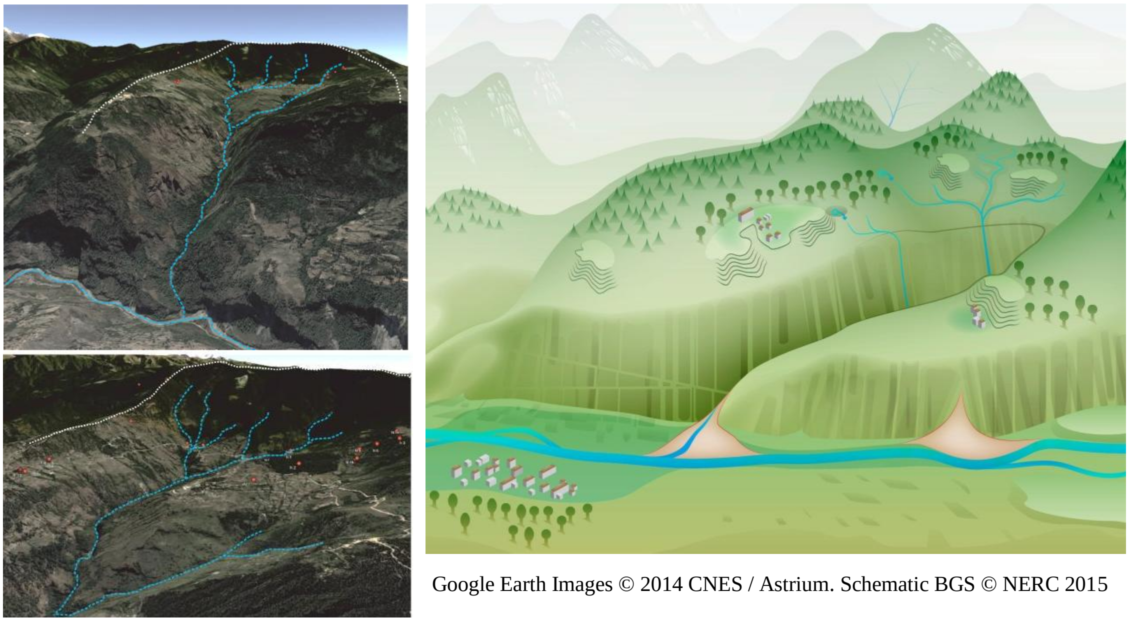



*Figure 28 - Stable isotope (O, H) results for the September 2013 and April/May 2014 sampling campaigns for a) all sites (Madanpokhara, Nangi and Ramche); b) Sites within Madanpokhara; c) sites within Nangi; d) sites within Ramche.*

### 4.2.2 Hydrogeological conceptual models

Below we present a preliminary conceptualisation of the groundwater systems present within the Middle Hills of Nepal, based on the observation from the two field visits, and the preliminary interpretation of the data. Three distinct hydrogeological environments are identified: a) hillslope springs; b) palaeo-lakes and smaller river floodplains, and c) river terraces and outwash deposits in the valley floor of large river systems.

**Groundwater in the hillslopes**



Google Earth Images © 2014 CNES / Astrium. Schematic BGS © NERC 2015

*Figure 29 - Geographical setting of groundwater in the hillslopes of the Middle Hills. White dotted line marks the catchment boundary. Blue dashed line shows the main stream network. Red notes denote sampling sites. Google Earth Images © 2014 CNES / Astrium*

*Geographical setting*: on the slopes of the Middle Hills, often near to or above the settlements on the valley sides, and valleys are drained by steep, deeply incised streams. Land use is a mixture of forest (either virgin forest or replanted after deforestation last century) and terraced agriculture.

*Geology*: Often thick, highly developed regolith and weathered bedrock zone overlying fractured basement comprising metamorphosed sandstones, gritstones and mudstones. Also poorly weathered rock exposures and areas of thin soil. There is negligible alluvium or any other superficial deposits.

*Aquife*r: Where present, regolith and thick weathered zone forms a productive shallow aquifer with high storage potential. The fractured bedrock provides a secondary aquifer with lower storage potential. The aquifer is recharged by snowmelt and monsoon rain; runoff is much greater where weathering is thinner. Where the weathered zone is thicker, there is significant storage and a greater potential for the retardation of groundwater flow paths.

*Groundwater supplies*. Groundwater discharge is almost exclusively through springs. These occur in two main types: as discrete issues at the base of a steep slope, or bowl; and more diffuse baseflow to deeply incised channels within weathered bedrock. Different seasonal variations and hydrological responses are observed for the two main spring types i) discrete springs tend to be less responsive with a more consistent spring flow during ISM and post-monsoon seasons though a reduction in springflow post-monsoon is noted at some sites, and ii) the diffuse springs, which tend to show large seasonal variations in spring flow throughout ISM season and post-monsoon season. Spring flows are typically perennial within the two study areas and minimum flow varies from approximately 0.3l/s – > 6l/s, significant increases in spring flow occur during monsoon season.

*Groundwater chemistry*: The springs have bicarbonate groundwater chemistry, with no dominant cation, indicating some water-rock interaction and a carbonate geology. No significant water quality concerns were detected, though higher silt content during the monsoon is reported. Stable isotope results suggest that the capture zone for the diffuse high slope springs is from higher elevations with a larger catchment area during the monsoon season gradually decreasing in size with an increasingly localised capture zone during post-monsoon – winter – pre-monsoon. Stable isotope results for the discrete springs show less seasonal variation suggesting that springs at these lower elevations have a more seasonally consistent capture zone.

*Resilience*: Diffuse springs issuing from the higher slopes are reliant on recent monsoon rainfall and snow to sustain higher flows, but baseflows are sustained by groundwater storage within the weathered aquifer and will therefore have some inter-annual storage. Discrete springs issuing from the base of lower slopes are most likely to be fed from groundwater storage within the fractured aquifer network. The relatively weak coupling of springs to recent rainfall implies some inter-annual storage. Groundwater residence time indicators (CFC and $SF_6$) suggest a mean residence time of 10-20 years for groundwater baseflow, implying again some in built resilience. However the general low storage of the groundwater environment suggests that none of the springs would be resilient to a long term reduction in precipitation.

The rapid decline in spring flows at many sites during the post-monsoon season suggests that much of the rainfall received during monsoon is discharged rapidly via the springs and incised stream channels. However the springs are perennial with groundwater storage in the weathered zone sufficient to support spring flow all year round. Groundwater age indicators (CFC and $SF_6$) suggest that the mean residence time for groundwater issuing from the springs is of the order of 10-20 years. Stable isotope results for the diffuse springs in the higher slopes suggest that a reduction in precipitation or changes in the seasonality of rainfall would result in a more restricted groundwater capture zone for the springs and a lower year round flow. Stable isotope results for the lower discrete springs suggest a more localised but seasonally consistent groundwater capture zone. These springs may therefore be less vulnerable to changes in seasonal rainfall but may be susceptible to changes in the spatial rainfall patterns.

Spring flow and water quality are vulnerable to changes in land use, for example deforestation, landslides and increased development. Springs at higher elevations in the Middle Hills are generally well protected at present by the presence and preservation of community forest land use. Springs at lower elevations in close proximity to roads and dwellings and are susceptible to development which alters local drainage and which give rise to potentially polluting activities. Where springs are at a lower elevation compared with the village it is harder to supply the spring flow to houses under gravity feed.

In the higher catchments of the Middle Hills (Ramche and Nangi) the springs are sufficient to meet the requirements of the existing population and agricultural industries and there is no evidence that the populations are growing significantly. In the lower catchment (Madanpokhara) it is apparent that the springs are insufficient to meet current water demands for residential and agricultural use during the dry season and shallow tubewells are used to supplement supplies. The population of Madanpokhara is increasing as is the agricultural industry.

## Palaeo-lakes and smaller river floodplains

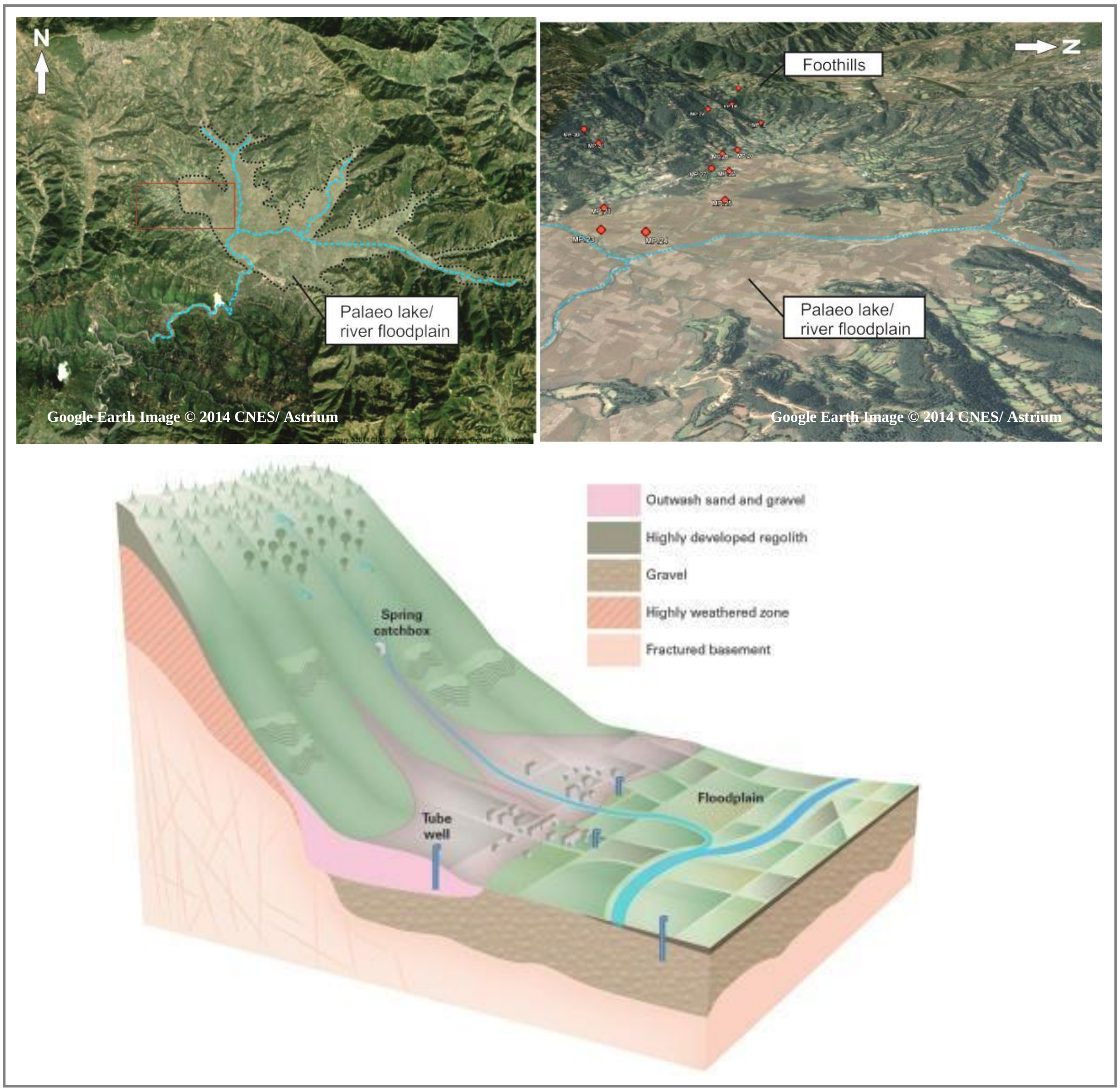



*Figure 30 - Geographical setting of groundwater within the smaller river floodplains. Blue dashed lines show main stream networks. Red dots denote sampled sites. Black dashed line marks the limits of the floodplain deposits. Schematic BGS © NERC 2015.*

*Geographical setting*: Middle Hills, palaeo-glacial lakes and the active river valley floodplain. The floodplain is used intensively for agriculture**.** Residential properties are located around the margins of the floodplain and on the shallow foothills.

*Geology:* Glaciofluvial - lacustrine deposits and overlying floodplain deposits within a river floodplain setting. Alluvial fan deposits and terraces occur at the lake margin.

*Aquifer*:

(i) Floodplain deposits, comprising glacio-fluvial, fluvial and lacustrine sediments. Fine sands and gravels form the main aquifer unit. Within the Madanpokhara catchment there is evidence of a black clay deposit which acts as a confining layer for the aquifer. Artesian groundwater conditions primarily occur during the monsoon season. However artesian groundwater levels were observed at one tubewell towards the centre of the floodplain during the pre-monsoon season. The aquifer is likely to be recharged by direct rainfall, floodwater and through groundwater-surface water interaction where the aquifer is unconfined.

(ii) Alluvial fan deposits and terraces at the lake margin, comprising outwash deposits, landslip materials and glacio-fluvial sand and gravel which form a high storage aquifer unit. The aquifer is likely to be recharged by direct rainfall and groundwater inflow from surrounding foothills.

*Groundwater supplies*: Shallow tubewells, fitted with handpumps and electric pumps, typically 20 – 30 m deep hand drilled into the floodplain deposits and within terraces/outwash deposits at the margin of the floodplain.

*Groundwater chemistry:*

(i) The floodplain deposits: form a confined aquifer with reducing conditions and sulphate reduction. Elevated iron and manganese concentrations are observed in several tubewells. Groundwater age indicators suggest a mean residence time of >50 years for the confined aquifer.

(ii) Alluvial fan deposits: The groundwater chemistry from tubewells located within alluvial fan or terrace deposits at lake margin is of better quality and more akin to that of springs in the surrounding foothills. Iron and manganese concentrations are not elevated. Stable isotope results suggest a localised groundwater recharge area for these aquifers. Groundwater age indicators suggest a mean residence time in the region of 10-20 years.

*Resilience*: Shallow tubewells located within the floodplain are reliant on recharge from rainfall and recharge from river floodwater and river-aquifer groundwater exchange. The large groundwater storage available within the unconsolidated deposits increases the resilience of these water supplies. However, the reliance on hand drilling and the use of suction pumps (with a maximum lift of 7 m) will make these water supplies vulnerable to overexploitation.

**River terraces and outwash deposits in the valley floor of large river systems**

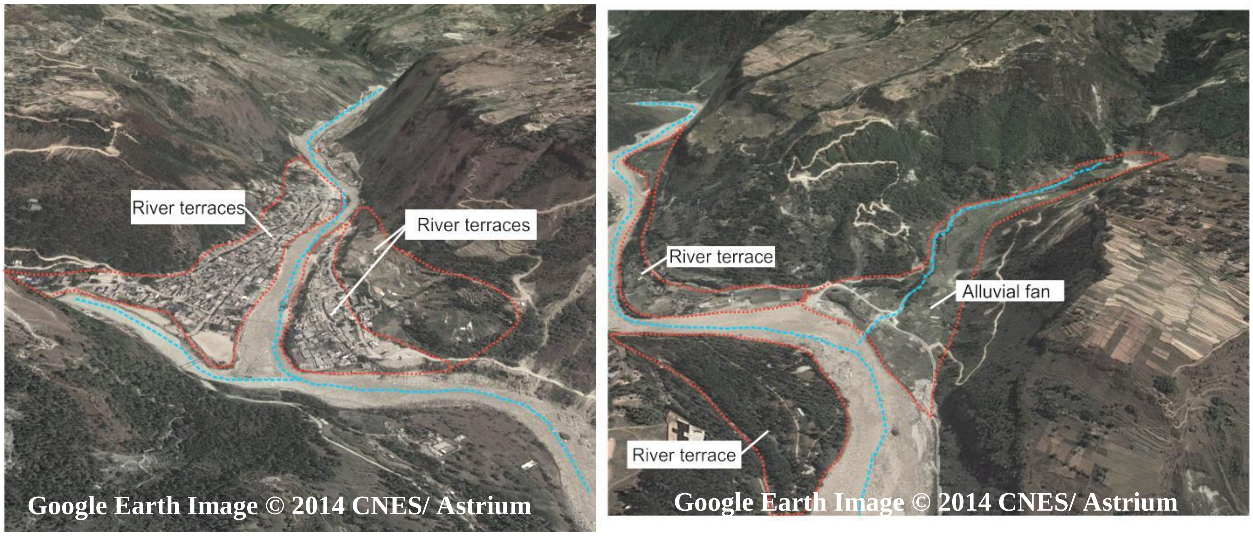



*Figure 31 - Geographical setting of groundwater in river terrace and outwash deposits in large river valleys. Blue dashed lines show the main river network. Red dashed lines mark the boundaries of the river terrace and alluvial fan deposits.*

*Geographical setting*: Valley floor and river floodplain of principal rivers draining the Middle Hills e.g. Kali Gandaki river. The river floodplain is broader and less incised than the tributaries which drain the higher slopes. River terraces and alluvial fans are developed for both residential and agricultural land use.

*Geology*: River terrace sand and gravels associated with present day and former cold-climate rivers, known locally at 'Tars'. The terraces deposits occur along most rivers in the Middle Hills and have a significant thickness in places. Alluvial fans, comprising glacio-fluvial outwash materials, occur at the confluence of tributaries draining the foothills with the wider river floodplains.

*Aquifer*: (i) River terrace sand and gravels. (ii) Alluvial fan glacio-fluvial deposits. The aquifers are likely to be in hydraulic continuity with the rivers, with the terraces providing additional river bank storage. Terraces dissected by incised channels are likely to be well-drained with a more limited saturated thickness. The alluvial fan aquifers may also be recharged by groundwater draining the foothills.

*Groundwater supplies*: Potential for high yielding shallow tubewells and large diameter wells to supply small towns. The current groundwater usage in this geographical setting is thought to be low.

*Groundwater chemistry*: Very little data for the groundwater chemistry of the river terrace deposits and alluvial fans exists and only one large diameter well in Beni was sampled during the field investigations. Groundwater chemistry results from the large diameter well show comparatively high concentrations of Boron, Rubidium, Molybdenum and Uranium indicative of the granitic geology within the wider river catchment and is consistent with hydraulic connection between the river and groundwater within the terraces. Stable isotope results indicate that groundwater recharge to the terraces at Beni is derived from higher elevations within the catchment, rather than local recharge.

*Resilience*: Only one site could be investigated as part of this study. Theoretically, the supplies are likely to be resilient, given the storage available within the aquifer, and the abundant recharge from the river. However, the supplies have other vulnerabilities, such as contamination from activity on the floodplain, and erosion of the terraces.

# 5 Summary and conclusions

Groundwater resources in the Middle Hills of Nepal perform a major role in supplying domestic and irrigation water and in regulating river flows. However, there has been little systematic study of groundwater within the Middle Hills, making it difficult to evaluate how water supplies and river flows may change in response to climatic and anthropogenic change. To begin to build an evidence base, two catchments in the middle hills were investigated to: characterise the hydrogeology of the catchments and wider hydrogeological setting; assess water supplies and water usage; and evaluate how resilient groundwater may be to change.

**Field work**

Two contrasting sub-catchments within the Kali Gandaki river catchment were investigated.

The first lies within Ramche VDC in Myagdi district and encompasses the villages of Ramche and Nangi. Ramche catchment lies at elevations of 1200 m to more than 3000 m with a sub-tropical to alpine climate. Land cover within the catchment is predominantly community forest, with terraced agriculture – agriculture is the primary source of income. Households are entirely reliant on springs for their water supply, some of which are captured upslope and supplied to the village, and others within the village where water is collected at the source.

The second catchment lies within Madanpokhara VDC in Palpa district. Madanpokhara catchment lies at elevations of less than 1000 m with a tropical to sub-tropical climate. Land cover in the catchment is dominated by agriculture, with little terracing, and there is some community forest on the hillslopes. Communities in Madanpokhara use a combination of springs and shallow tubewells to meet their water requirements. Madanpokhara is a drier catchment and entirely reliant on monsoon rain.

Fieldwork was undertaken during the post-monsoon season (16$^{th}$ – 26$^{th}$ September 2013) and pre-monsoon season (23$^{rd}$ April – 7$^{th}$ May 2014). Thirty-one sites across the two catchments were investigated using a combination of water supply surveys, spring flow and temperature measurements, and sampling for inorganic chemistry, stable isotope and groundwater residence time and noble gas indicators. In addition 12 months of weekly hydrological monitoring and monthly water usage surveys were undertaken at seven springs.

**Preliminary Findings**

Based on the observations from the two field visits and a preliminary interpretation of the data some initial findings are provided below. The data will be further analysed and interpreted in subsequent peer reviewed papers.

- There are contrasts in population trends and land use within the two catchments: in the higher catchment in Ramche VDC, land is predominantly community forest with locals largely employed in subsistence farming on terraced slopes. Population was steady, with outward migration matching increased birth rates. Community members were concerned about a skills shortage to sustain the agricultural land. In recent years there has been a shift from cereal crops to vegetable farming. Locals in Ramche VDC are concerned about drying of the springs and increased prevalence of pests and diseases affecting the forest. Water scarcity is a concern during the pre-monsoon season and there is a government initiative to install further water supply sources in Ramche VDC using stream water. In the lower catchment in Madanpokhara VDC land is predominantly cultivated for commercial vegetable farming with crops sold in nearby towns. An influx of people to Madanpokhara as a result of the growing agricultural industry is placing increasing pressure on water supplies with growing populations and increased irrigation of land. Locals in Madanpokhara VDC are concerned about the insufficiency of spring water. However, the growing abstraction of groundwater through tube wells has underpinned the rapid expansion of irrigated agriculture, and arguably, the springs flows are becoming less important.

- There is a heavy reliance on springs for water supply in the Middle Hills, particularly at higher altitudes. Two principle types of springs have been identified i) diffuse springs which emanate from higher slopes and discharge to form the headwaters of incised mountain streams, and ii) discrete springs which appear to issues at topographical lows at lower elevations. The springs are typically perennial but with significantly reduced flows during the winter and pre-monsoon season. The springs have bicarbonate groundwater chemistry and general low overall mineralisation.
- Diffuse springs issuing from the higher slopes are reliant on recent monsoon rainfall and snow to sustain higher flows, but baseflows are sustained by groundwater storage within the weathered aquifer and will therefore have some inter-annual storage. Discrete springs issuing from the base of lower slopes are most likely to be fed from groundwater storage within the fractured aquifer network. Their relatively weak coupling to recent rainfall implies some inter-annual storage. Groundwater residence time indicators (CFC and $SF_6$) suggest a mean residence time of 10-20 years for baseflow, implying again some in built resilience. The general low storage of the groundwater environment suggests that none of the springs would be resilient to a long term reduction in precipitation.
- Stable isotope results for the diffuse springs in the higher slopes suggest that a reduction in precipitation or changes in the seasonality of rainfall would result in a more restricted groundwater capture zone for the springs and a lower year round flow. Stable isotope results for the lower discrete springs suggest a more localised but seasonally consistent groundwater capture zone. These springs may therefore be less vulnerable to changes in seasonal rainfall but may be susceptible to changes in the spatial rainfall patterns.
- Spring flows and water quality are vulnerable to changes in land use, for example deforestation, landslides and increased development. The presence of community forest land use in the higher slopes of the middle hills makes springs in these locations less vulnerable than springs nearer the settlements.
- There is anecdotal and field evidence of water scarcity during the pre-monsoon season, where spring flow is insufficient to meet the demands of the community. In some cases spring flow from larger springs is diverted to other supplies to meet demand while some households in Madanpokhara re-use domestic water on agricultural land. Formal water storage structures in the catchments are limited.
- In the lower catchment of Madanpokhara where floodplain and outwash deposits are present a proliferation of manually drilled shallow tubewells have been installed in the last 5-10 years. Groundwater abstracted from these tubewells is largely used for irrigation of agricultural land, use of the groundwater for domestic purposes is more-limited. The development of these groundwater resources has resulted in a thriving agricultural co-operative, secure livelihoods, inward migration and a growing population. It is unclear whether recharge to the floodplain aquifer balances groundwater abstracted from it. These shallow tubewells have increased the resilience of the local communities but are potentially vulnerable to over-exploitation as a result of population increase and economic growth as well as being sensitive to polluting activities.
- Groundwater sampled in tubewells along the margin of the floodplain is modern (~20 yrs MRT) with bicarbonate groundwater chemistry and no significant water quality concerns.

Groundwater sampled from tubewells towards the centre of the floodplain appears to be older (~50 yrs MRT) with elevated concentrations of iron, manganese and arsenic detected at some sites.

**Further work**

To strengthen the evidence base in the Middle Hills, on-going flow and temperature monitoring of the springs sources is being undertaken by ISET-Nepal and a further 6 months of stable isotope samples have been collected and will be tested by the BGS laboratory. Once all data are available the following outputs will be developed: (1) data for the local Nepali communities; (2) a paper on groundwater within the Middle Hills; and (2) a second paper presenting the use of groundwater in Madanpokhara and the evolution of groundwater chemistry from the hillslopes through to the floodplain.

With a growing recognition of the importance of groundwater storage in the middle hills there is significant potential to further advance the characterisation of groundwater systems and investigate their resilience to change. Clearly, there is much work to be done. Systematic monitoring of groundwater, as springs flows, groundwater levels and chemistry would give a much better understanding of emerging trends. Likewise, monitoring current yields of springs and comparing to historic values at installation may allow some conclusions to be drawn about the trajectory of springflow. There are several initiatives underway within Nepal; the lessons learned from this current research, the methodologies used and the preliminary findings will be of value to these:

- ISET-Nepal has initiated a transboundary groundwater study in three Terai districts of Nepal in conjunction with Megh Pyne Abhiyan (MPA), Water Action and Advanced Center for Water Resources Development and Management (ACWADAM) of India. The scope of the study includes contextualizing transboundary water, with special reference to aquifers and participatory groundwater management in India and Nepal.
- ISET-Nepal, in collaboration with the Groundwater Resource Development Board, has undertaken some preliminary groundwater mapping of Nepal.
- IWMI has started a five-year research project on Nepal's Middle Hills, funded by the Asia Development Bank (ADB). The project will investigate the hydrology of the Middle Hills, in particular the spring systems, and will focus on two river catchments in Western Nepal, near West Seti.
- ICIMOD are undertaking a short-term innovation project to assess springs in the water-deficient catchments of Jhikhu and Namo Buddha in Kavre district, east of Kathmandu. Rainfall data, spring flow data and information on water usage and water management practices will be collected as part of the project.
- The Groundwater Resources Development Board (GWRDB) has long-term aims to monitor springs in the middle hills. Inventories of the catchment springs are being collected and surveys of newly-drilled shallow tubewells in the Middle Hills are being undertaken. The GWRDB is also considering drilling observation boreholes on the metamorphic sediments of the middle-hills. In order to improve their groundwater testing capability the GWRDB have invested in laboratory equipment for groundwater stable isotope analysis.

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# Appendix 1 Field data

## A1.1 Sampling site locations

| ID | Site | Sample type | Latitude (Degrees) | Longitude (Degrees) | Sample no. Sept 2013 | Sample no. April/ May 2014 | GW chemistry | Stable isotope | $CFC/SF_6$ | Spring flow/temp | Stream levels | Noble gases |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N.1 | Tallopadhera, Nangi | Spr | 28.36847 | 83.63953 | | 1 | | | A | | | |
| N.2 | Setod Hunga, Nangi | Spr | 28.36462 | 83.64171 | | 2 | | | A | | | |
| N.3 | Ratojhapra, Nangi - sample point | Spr | 28.35569 | 83.64422 | 8 | 3 | | L | B | | | B |
| N.3b | Ratojhapra, Nangi - source point | Spr | 28.35526 | 83.64605 | | 3b | | | | | | |
| N.4 | Seto Kharsu, Nangi - sample point | Spr | 28.35906 | 83.64407 | 10 | 4 | | L | B | | | S |
| N.4b | Seto Kharsu, Nangi - source point | Spr | 28.35966 | 83.64266 | | 4b | | | | | | |
| N.5 | Inar, Nangi - sample point | Spr | 28.36428 | 83.64811 | | 5 | | | A | | | |
| N.5b | Inar, Nangi (Bottom) | Spr | | | | 5b | | | | | | |
| N.5c | Inar, Nangi - Source point (Top) | Spr | 28.36422 | 83.6482 | | 5c | | | | | | |
| N.6 | Seasonal stream, Nangi | Stream | 28.35745 | 83.6445 | 9 | | | | | | | |
| N.7 | River Dobilla, Nangi | Stream | 28.3662 | 83.64925 | 11 | | | | | | | |
| N.8 | Lake at Nangi | Lake | | | 17 | | | | | | | |
| R.9 | Sano Gaunmul, Ramche | Spr | 28.38562 | 83.64291 | | 6 | | | A | | | |
| R.10 | Thulo Mul Padhero, Ramche village - sample point | Spr | 28.38616 | 83.63913 | 12 | 7 | | L | B | | | B |
| R.10b | Thulo Mul Padhero, Ramche village - source point | Spr | 28.38657 | 83.63924 | | 7b | | | | | | |
| R.11 | Citeni Mul sample point | Spr | 28.38236 | 83.67153 | 13 | 8 | | L | B | | | S |
| R.11b | Citeni Mul - source point (top LHS tributary) | Spr | 28.38236 | 83.67153 | | 8b | | | | | | |
| R.11c | Citeni Mul - (lower LHS tribuatry, above sample point) | Stream | 28.38236 | 83.67153 | | 8c | | | | | | |
| R.11d | Citeni Mul - (RHS tributary, above sample point) | Stream | 28.38236 | 83.67153 | | 8d | | | | | | |
| R.11e | Citeni Mul - (tributary below sample point) | Stream | 28.38236 | 83.67153 | | 8e | | | | | | |
| R.12 | Khalna (GW seepages), Ramche | Spr | 28.38086 | 83.6559 | 14 | 9 | | | A | | | |
| R.13 | Chhre, Ramche - stream two | Stream | 28.37455 | 83.65545 | 15 | | | | | | | |
| R.14 | Stream on the way from Ramche to Nangi | Stream | 28.37275 | 83.65453 | 16 | | | | | | | |
| TP.15 | Tato Pani | Hot Spr | 28.49626 | 83.65437 | | 10 | | | A | | | |
| TP.16 | Tato Pani Singha | Hot Spr | 28.3677 | 83.50252 | | 11 | | | A | | | A |
| B.17 | Baurah, Beni Borehole source | LDW | 28.3542 | 83.56619 | | 12 | | | A | | | |
| B.17b | Baurah, Beni - sample from main river | Stream | 28.3542 | 83.56619 | | 12b | | | | | | |
| MP.18 | Bhaun Khola, Madanpokhara (stream) | Stream | 27.83088 | 83.55663 | 2 | - | | | | | | |
| MP.19 | Bhaun Khola Jukedhara, Madanpokhara - source | Spr | 27.82826 | 83.55269 | 3 | 13 | | L | B | | | S |
| MP.20 | Community lodge no.7, hand pump Madanpokhara | TW | 27.82948 | 83.56365 | 4 | 14 | | | A | | | A |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MP.21 | Handpump 2 - roadside house | TW | 27.82306 | 83.57529 | | 15 | | | A | | | |
| MP.22 | Damkada Tari, handpump 3 Madanpokhara | TW | 27.82929 | 83.56844 | 7 | 16 | | | A | | | |
| MP.23 | Handpump 4 - river floodplain | TW | 27.82372 | 83.57851 | | 17 | | | A | | | |
| MP.24 | Handpump 5 - floodplain artesian | TW | 27.82601 | 83.5788 | | 18 | | | A | | | |
| MP.25 | Handpump 6 - floodplain house | TW | 27.82952 | 83.57404 | | 19 | | | A | | | |
| MP.26 | Handpump 7 - roadside | TW | 27.82851 | 83.56461 | | 20 | | | A | | | |
| MP.27 | Handpump 8 - terrace edge | TW | 27.82811 | 83.56795 | | 21 | | | A | | | |
| MP.28 | Majhi Dhara, MP | Spr | 27.82861 | 83.54936 | | 22 | | | A | | | |
| MP.29 | Badkhola Mal, Madanpokhara - source | Spr | 27.82651 | 83.5551 | 5 | 23 | | L | B | | | B |
| MP.30 | Andheri (higher; Vulture), MP | Spr | 27.81879 | 83.56328 | | 24 | | | A | | | |
| MP.31 | Andheri Chareharee (lower), Madanpokhara - source | Spr | 27.8202 | 83.56503 | 6 | 25 | | L | S | | | S |

Spr – spring
Hot Spr – hot spring
TW – tubewell
LDW – large diameter well
Stream – stream/river

Green shading denotes sample collected
*L – Long-term monitoring for stable isotopes
B - Samples collected in both Sept. 2013 and April/May 2014
S - Sample collected in Sept. 2013 only
A - Sample collected in April/May 2014 only