Geological Mapping and Its Importance for Construction Material, Water Chemistry, and Terrain Stability in the Jhikhu and Yarsha Khola Watersheds

Gopal Nakarmi
PARDYP-MNR Division, International Centre for Integrated Mountain Development

Abstract

Geological studies were conducted in the Jhikhu (JKW) and Yarsha Khola watersheds (YKW) to document the rock types and their role in agricultural and rural industrial activities. Field investigation revealed that quartzite, limestone, selected bands of sandstone, and marble are quarried at different locations for short periods of time in the JKW, whereas quartzite, some gneiss and to a lesser extent black slate are currently excavated in the YKW. In both watersheds, local residents are currently mining primarily for local consumption.

In the JKW, water draining the quartzite and sandstone contained fewer soluble minerals and had low average runoff conductivity values (50 and 75 µS/cm, respectively). Soils derived from these rocks had a low cation exchange capacity and are thus highly sensitive to acidification. In contrast, carbonate rocks such as marble, limestone, and dolomite contributed the highest quantities of water-soluble minerals, and had higher conductivity values (average 375 µS/cm). The soils formed from these rocks contained higher levels of cations, and thus have a greater capacity to buffer acidic conditions.

Using GIS overlay and query techniques, a composite map was generated of vulnerable units in geology, surficial material, elevation, slope, aspect, and land use. This map can be considered as a map of potential instability; areas at risk had the same configuration as the currently unstable areas. All the areas of potential risk (620 ha)—the degraded areas—were concentrated at sites where all the critical geological, topographical, and land use factors were dominant.

Introduction

Understanding of rock types and their role in agricultural and rural industrial activities is important for the economic growth of mountain communities in both the Jhikhu and Yarsha Khola watersheds. As well as being a key local building resource, competent rocks also modify the quantity and quality of water that passes through them, have a direct influence on soil fertility, and play a key role in terrain stability.

Geological surveys were undertaken in early 1997 and 1998 in the Jhikhu and Yarsha Khola watersheds in order to map the spatial distribution of the major rock formations . The rock types were identified, the attitudes of bedding plane recorded, and prominent structural features traced. Of the eight formations identified in the Jhikhu Khola watershed (JKW), only sandstone, quartzite, limestone, and marble are selectively mined for local use. Five geological formations were identified in the Yarsha Khola watershed (YKW), and of these only two, quartzite and some black slate, are currently quarried by local farmers. Stone products are mostly sold only locally.

Carbonate rock influences the runoff conductivity of water and affects its pH. The amount of cations present in the soils developed from these rocks is high compared to those in soils from schist and gneiss.

Stability was also investigated. The rocks near the Mahabharat thrust in the JKW are heavily folded and crushed and thus form a fragile belt prone to landslides. In contrast, the synclinal fold stretching from Ghoredhunga to Mirge in the YKW displays a stable landform with well-developed thick red soils on top.

Site Location and Methodology

The Sites

The locations of the two watersheds studied are shown in Figure 102. The JKW covers 11,100 ha, has an elevation range from 800 to 2,100m, is situated 45 km east of Kathmandu, and is accessible via the Arniko highway. Fifty-five per cent of the JKW is currently under agriculture, with about two-thirds rainfed land and one-third under irrigation. The YKW covers about 5,300 ha, has an elevation range from 1000m to 3000m, is located 190 km north-east of Kathmandu, and is accessible via the Lamusangu-Jiri highway. Fourteen per cent of the watershed is irrigated agricultural land and 37 per cent rainfed agricultural land. The main difference between the watersheds is the distance to market—the JKW is in close proximity to markets and has undergone more rapid agricultural intensification and population growth than the YKW. Table 85 shows the increase in the number of houses during the period 1990 to 1996 (JKW) and 1961 to 1996 (YKW).

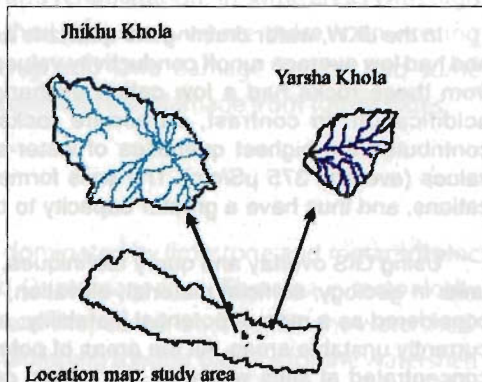

Figure 102: **Location of the Jhikhu Khola and Yarsha Khola watersheds**

Stones are the largest visible natural resource in Nepal (UNDP 1977). Increasing house construction activities in both watersheds demand appreciable quantities of stone. The production and utilisation of stones is labour intensive, but if properly managed can have a significant impact on the local economy.

Table 85: **Increase in the Number of Houses in the Two Watersheds**			
Watershed	1961	1990	1996
Jhikhu Khola Yarsha Khola	No data 285**	5474* No data	8002* 3640**
Sources: *Shrestha 1998; **Jordan and Shrestha 1998			

Methodology

Conspicuous bedding planes and prominent structural features were provisionally identified on aerial photographs (scale 1:25,000) and verified in the field. During field surveys, 750 sites with rock exposures were examined in the JKW and 500 sites in the YKW. The attitude of the bedding plane, the nature of contact between beds, the structural features, and the rock types were recorded on a 1:25,000 scale topographic map.

The chemistry of rainwater changes while moving through rocks that contain soluble minerals. Runoff conductivity is often a good natural indicator of the quality of the rock formation spread in the vicinity. A conductivity meter and pH probe were used to examine the chemical condition of stream and spring water during low flow conditions, when rock-water interactions are most pronounced.

Stream flows were measured at sub-watershed outlets in the JKW during the dry period when the chemical contribution from the rocks to the water flow is high. Observation points were marked on the topographic map, as were major geomorphic features of instability like landslides, gullies, rills, and bank erosion.

All existing degraded areas including landslides, gullies, rills, and eroding stream banks were provisionally identified on aerial photographs, and then verified and cross-checked in the field. A geomorphic process map was thus created and then digitised into a GIS; previously digitised information on elevation, geology, surficial material, and land use maps assisted in the analysis.

The following were identified using GIS overlay and query techniques: the most dominant elements in topography (including elevation, slope, and aspect); geology (encompassing lithology and surficial material); and the relationship between land use category and instability. A composite map was produced which showed areas at the highest risk of instability (Nakarmi 1996).

Results

Geology and Building Material

The JKW

Two geological domains were identified in the JKW. The upper domain belongs to the Lower Kathmandu Complex and overlays the lower domain, which is part of the Upper Nuwakot Complex. These domains are separated by the regional tectonic plane known as the

Mahabharat Thrust (Stöcklin and Bhattaria 1981). Six lithological formations belonging to the Lower Kathmandu Complex are characterised by, from top to bottom, meta-sandstone, schist and quartzite intercalation, mica schist, quartzite, marble, and garnetiferous mica schist. The dominant rocks underlying the Upper Nuwakot Complex are a dark grey slate, intensively folded green schist, grey phyllite, limestone, and dolomitic limestone (Figure 103).

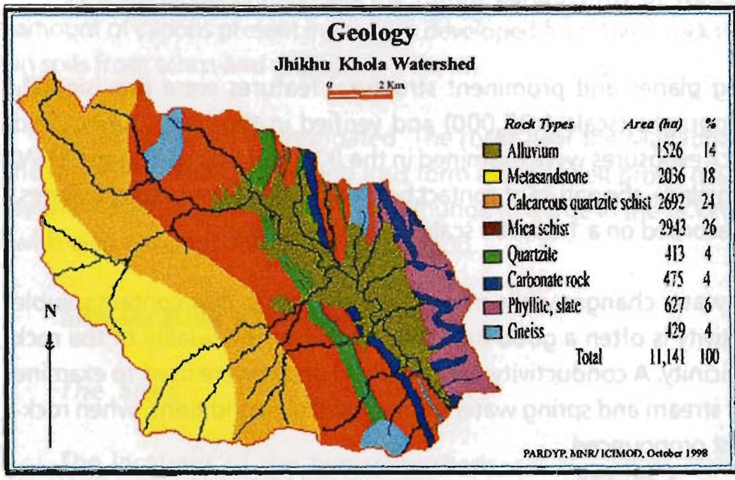

Figure 103: **Geological Map of the Jhikhu Khola Watershed**

The slate and limestone near the thrust plane are intensively crushed and several landslides are active particularly near the south-east corner. These rocks are considered to be from the Paleozoic period while the Lower Kathmandu Complex belongs to the Precambrian to early Paleozoic period. The predominant bedrock alignment is in the NW-SE direction with moderate to steep dips towards the south-west.

Quartzite, limestone, selected bands of sandstone and marble are quarried at different locations for short periods of time mainly for local consumption in the JKW, which is undergoing rapid development in terms of house and road construction. The present demand for stones as a major construction material is huge. As a result of the lack of any clear policy on stone excavation, quarries start and shut down over periods of a few weeks or a month creating frequent shortages, especially in seasons when house and road construction take place (autumn and winter).

Unfortunately for many, stones of acceptable quality and quantity are often located in the forested areas that are managed by communities, and under the present arrangements only community members have access to such rocks which cannot be sold to outsiders. Non-members of these fortunate communities must look for other sources. Currently, river channels are the easiest alternative, but such practices are leading to a rapid depletion of stones along the Jhikhu Khola and its tributaries. This has caused a three-fold problem:

- the stones required for repairing the weirs that frequently break during major storms are no longer available and stones for this purpose have to be transported into the watershed from outside;

- river scouring and bank cutting processes are intensified and the most productive lands adjacent to the river channels are more frequently damaged and sometimes destroyed; and
- serious environmental problems result that are threatening the aquatic biota.

A clear-cut policy is needed on stone excavation because the competent rocks suitable for construction are scarce and without a proper excavation policy many local residents do not have access to these vital resources. Community groups need to be more involved in environmental protection activities, including afforestation of quarries after completion of excavation activities. This will reduce the pressure on the river channel.

The YKW

The geological materials of the YKW consist of low to medium grade metamorphic rocks. Graphitic schist and dark slate form the core of the synclinal fold, the axis of which stretches from the main hydrological station towards Mirge, gently dipping east. Black schist is underlain by a succession of talc, magnesite, and medium to thickly bedded quartzite, which is intercalated with grey schist. Although the quartzite bed generally forms narrow bands, its exposure widens around Khaniyachaur, north-west of Thulichaur and Yarsha (Figure 104). Green phyllite and chlorite schist underlay the quartzite bed. Below these rocks is gneiss, which occupies the base of the geological section in the YKW. Gneiss (31%) and phyllite (19%) are widely exposed on both flanks of the syncline. An anticlinal axis passes through Dahaltar and Khaniyachaur where thickly bedded quartzite forms the core of the anticline. Quartzite, some gneiss, and to a lesser extent black slate are currently mined by the residents in YKW, primarily for local use.

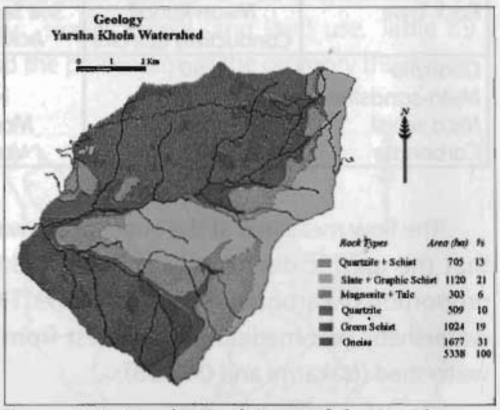

Figure 104: **Geological Map of the Yarsha Khola Watershed**

Proper support guided by clear policies for stone quarry management will enhance the capacity of the local community to develop these resources for economic development. A road link to the quarry site might lead to significant economic development in the north-east block of the YKW.

Geology versus Water Chemistry

Water chemistry surveys were conducted during the dry season when the influence of rocks on water flowing through them is most marked. The electrical conductivity of water is a good indicator of the quality and type of the bedrock, with carbonate rocks giving very high values and quartzite generally low values.

The JKW

Water draining the quartzite and sandstone contained fewer soluble minerals and had average conductivity values of 50 and 75 μS/cm respectively (Table 86). Similarly, the soils derived from these rocks had a low cation exchange capacity and are consequently highly sensitive to acidification. Carbonate rocks such as marble, limestone, and dolomite contributed the highest quantities of water-soluble minerals: water draining these rocks had higher conductivity values averaging 375 μS/cm. The soils formed from these rocks had higher levels of cations, and thus have a greater capacity to buffer acidic conditions. The runoff conductivity of water from mica schist terrain was moderate and the soil derived from these rocks was moderately sensitive to acidification.

Table 86: **Rock, Water, and Nutrient Status in the Jhikhu Khola Watershed**

Rock Type	Mean Runoff Conductivity (µS/cm)	Soil Sensitivity to Acidification	Soil Cation Level	No. of Soil Samples Analysed
Quartzite	50	High	Low	23
Meta-sandstone	75	High	Low	17
Mica schist	157	Moderate	Medium	13
Carbonate	375	Very low	High	8

The flow measured at the outlet of subwatersheds in the JKW during dry periods showed that the specific discharge was highest (3.5 l/min/ha) from the area containing a large proportion of carbonate rocks (Table 87). The discharge from sandstone-dominated sub-watersheds was medium, and lowest from the mica schist and phyllite-dominated sub-watershed (Nakarmi and Li 1998).

Table 87: **Water Flow Conditions by Major Rock Types in the Jhikhu Khola Watershed**

Mean Specific Discharge (l/min/ha)	Dominant Bed Rock Type in the Sub-watershed	Number of Observations
3.5	Carbonate rock	2
1.7	Sandstone	4
0.3	Mica Schist + Phyllite	12

The YKW

The influence of rocks on water was also clearly visible in the YKW. There are few water-soluble minerals in gneissic rocks, and the runoff water from these rocks had the lowest conductance (average 32 μS/cm) and a mean pH of 7.1 (Table 88). The soils generated from these rocks were poor in cations and are thus highly susceptible to acidification. Runoff water from the schist and quartzite rocks (with mica partings) had moderate conductivity values and the amount of cations in the soils from these rocks was moderate. Magnesite, dolomite, and limestone release bicarbonate and carbonate, as a result the runoff water was harder and had a high conductivity (387 μS/cm) and high pH (8.3). The amount of cations in the soils from these rocks was much higher, which makes them less vulnerable to acidification. Both carbonate rocks themselves, and the water released from these rocks, can be used to amend soil acidity.

Table 88: **Rock – Water – Nutrient Status in the Yarsha Khola Watershed**

Rock Type	Mean Runoff Conductivity (μS/cm)	Average pH	Soil Sensitivity to Acidification	Soil Cation Level	Number of Soil Samples
Magnesite + Talc	387	8.3	Very low	High	5
Quartzite + Schist	189	8.2	Low	Moderately High	19
Slate + Graphitic Schist	167	7.9	Low	Moderately High	13
Quartzite	124	7.7	High	Low	9
Green Schist	112	7.5	High	Low	22
Gneiss	32	7.1	High	Low	42

Geology versus Terrain Stability

In order to identify the most vulnerable areas in the JKW, a geomorphic process map depicting all existing degraded areas was overlaid with maps of six different themes or categories: geology, surficial material, elevation, slope, aspect, and land use. Table 89 indicates the vulnerable units in each category and the percentage of the category they cover.

A second GIS overlay and query were performed on vulnerable units in geology, surficial material, elevation, slope, aspect, and land use without the map of currently unstable sites. The composite map (Figure 105) can be considered as a map of potential instability, since it shows areas with the same configuration as the currently unstable areas. This map shows that the degraded areas, which comprised 139 ha or 22 per cent of the total 620 ha area of potential risk, were located at sites where all the critical geological, topographical, and land use factors were present.

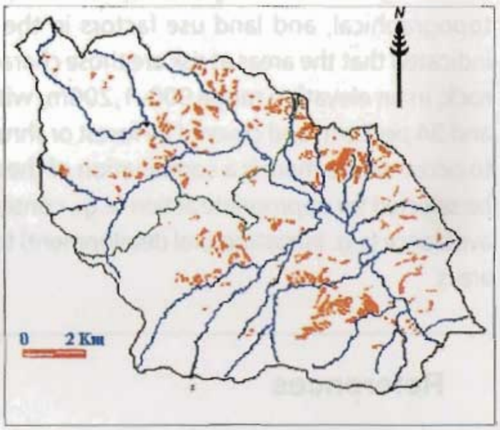

Figure 105: **Potentially Unstable Sites**

Degraded lands are generally left unattended. Figure 105 shows the areas where rehabilitation activities need to be carried out. It is clear that infrastructure development activities should be avoided at such sites.

Table 89: **Vulnerable Units in Each Category in the Jhikhu Khola Watershed**

Category	Vulnerable Units	Percent Within Each Category
Geology (bed rock)	schistose quartzite + mica schist	64
Surficial material	residual soil + rock	90
Elevation range (m)	900-1199	71
Slope (%)	5–34	50
Aspect	south + east	64
Land use	forest, shrub +others	77

Conclusion

Excavation of competent rocks is the backbone of residential and infrastructural development in the JKW and the YKW. However, a clear policy is needed for stone excavation activities to systematise quarry operations. This policy should ensure a regular and adequate supply of appropriate construction materials for a greater number of people. This would relieve pressure on the boulders in the riverbeds, which are essential to protect the channel and for repairing the diversion structures that frequently break during flood events.

Carbonate rocks released a greater proportion of soluble mineral into the draining water than quartzite and schist. The runoff conductivity of the water draining carbonate terrain was high, with a mean of 375 $\mu S/cm$. In contrast, the runoff water from quartzite had a low cation content resulting in low conductivity values (less than 50 $\mu S/cm$). The runoff conductivity measured in streams during low flow conditions was a useful descriptor of bedrock conditions and gave a good indication of the resilience of soil against acidification.

Using the GIS overlay technique, it was possible to determine the dominant geological, topographical, and land use factors in the currently degraded areas of JKW. This work indicated that the areas at risk are those characterised by mica schist and schistosed quartzite rock, in an elevation range 900–1,200m, with a south or east aspect, on slopes between 5 and 34 per cent, and covered by forest or shrub land. The greatest risk of degradation is likely to occur where there is a combination of these factors. These results enable priority areas to be selected for appropriate action (e.g., conservation, change of land use or management) or avoidance (e.g. infrastructural development) to prevent further degradation in the most prone areas.

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