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Role of bedrock on stream conductivity and groundwater contribution to streams: a case study from Jhikhu Khola watershed, central Nepal

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ABSTRACT

Role of rock formations on water conductivity and groundwater condition contributing to stream flow was examined in the Jhikhu Khola watershed, central Nepal. More than 75% of annual rainfall occurring between June and September which recharges the groundwater. Carbonate rocks are responsible for the higher conductivity values whereas mica schist and quartzite yield little flow with low conductivity during dry season. For better understanding of the water storage capacity of the rock formations, detail studies on distribution of fissures and cavities in the rocks are essential. Application of selected tracer will assist to evaluate flow direction and quantify the rate of flow.

INTRODUCTION

Socio-economic survey (Shrestha and Brown, 1995) has identified water shortage as one of the main constraints in agricultural development of the Jhikhu Khola watershed. Improvement of farmers' livelihood is also dependent upon access to safe water. To ensure a safe and sustainable water supply, water balance determination is a primary step. For this, we have to know where and how much water enters the watershed via rainfall, how much is evaporated and what amount of water is in storage that can be drawn either on a daily or annual basis. The water stored at the surface (reservoirs, lakes) is easy to quantify, but the determination of groundwater storage in mountain aquifers is far more challenging. Artificial surface storage is difficult in this terrain because of lack of suitable sites, high evaporation rates, and leakage losses through the steeply dipping and highly fractured bedrock.

Groundwater is rapidly emerging as key future source of water supply for domestic and agricultural purposes but with it comes the difficulties of detecting new sources and quantifying the amount and quality of the water. This paper attempts to document the influence of bedrock on the water flow and quality in the Jhikhu Khola watershed. The data are derived from the monitoring of rainfall variation, the determination of air temperature fluctuation, measurements of stream flows and electric conductivity of stream waters. The field measurements of the stream discharge and water conductivity were carried out during lean flow period because it is at that time of the year when the contribution of groundwater to the stream is the greatest. Flow measured at 18 spots and conductivity at about 100 sites were analysed and the data were incorporated into a Geographic Information Systems (GIS) database. The geological and rainfall data were also added to the GIS system and the relationships between the geology, stream flow and stream water conductivity were determined.

STUDY AREA

The study area is located 40 km east of Kathmandu, in the middle hill of central Nepal (Fig. 1) and is connected with capital by the Arniko

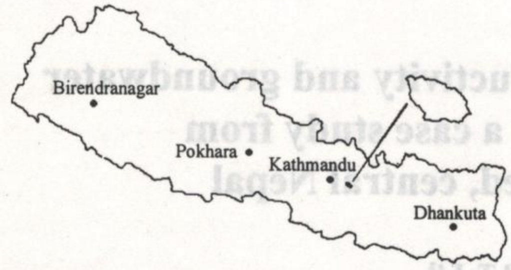

Fig. 1: Location of Jhikhu Khola watershed.

Highway. It covers an area of 110 km^2, which lies between latitudes 27°36'N and 27°41'N, and longitudes 86°32'E and 86°41'E, and confined within the altitude range of 800-2000 m. The annual average rainfall is 1300 mm, mean maximum and minimum temperatures are 38°C and -2°C, respectively. Fifty four percent of the watershed area is under agricultural use, of which intensively cultivated low land sites demand high water inputs. The stream discharge in the Jhikhu Khola is highly variable from 0.01 m^3/sec in dry season to more than 100 m^3/sec during peak storms in the monsoon.

METHODOLOGY

Geological survey was conducted in early 1997 using topographic base map and aerial photographs (1:25,000 scale) and verified with intensive field checking. Major rock formations and fault zones were identified and plotted on the map.

The daily rainfall, maximum, and minimum temperatures are recorded in six meteorological stations, which were established at different time. Data recorded from 1990 to 1996 at Tamaghat, Dhulikhel and Bela, and data from 1993 to 1996 recorded at Baluwa, Bhimsensthan and Bhetwalthok are subjected to analysis.

Electric conductivity of stream water was measured during dry period when the contribution of the base flow is maximum, using digital conductivity meter. The unit is micro Seimens per centimetre (µS/cm) and all values were plotted onto the map. The watershed is divided into eighteen sub-watersheds (Fig. 2) to measure the flow. The field measurements were conducted in early June before the onset of monsoon storm. Prior to any measurement, the stream channel was first prepared

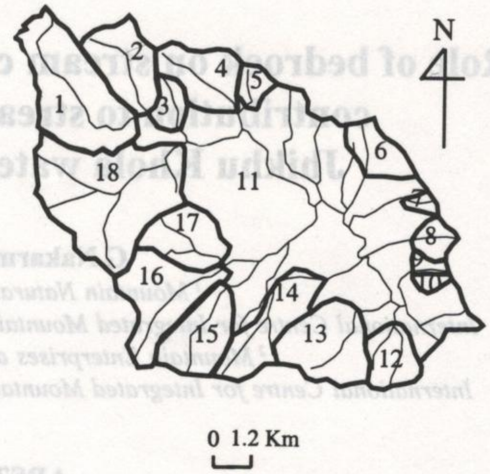

Fig. 2: Sub-watersheds (1- 18) for flow measurements.

to produce uniform flow through the section and stream velocity was recorded using "Price AA" current meter. The calculated discharge value is divided by the area of each drainage basin to obtain its specific discharge. All the data are spatially related, integrated, and analysed using GIS.

RESULTS

Geology

The thrusting of medium grade metamorphic rocks of the Kathmandu Complex over low grade metamorphics of the Nawakot Complex had reshaped the geological configuration of the Jhikhu Khola watershed. In the field, the roughly northwest-southeast trending Mahabharat Thrust forms a distinct boundary between medium grade rocks and underlying low grade geological domain. The geological succession of upper domain is composed of garnetiferous mica schist at the base, marble, micaceous quartzite, with augen gneiss at the middle part followed by metasandstone at the top. It belongs to the Precambrian to Lower Cambrian in age of the Bhimphedi Group of the Kathmandu Complex, which is partially truncated in the study area. The rock succession of underlying domain belongs to the Lower Nawakot Group of the Nawakot Complex that comprises of predominantly phyllite with subordinate quartzite interbedded with highly folded limestone, dolomite and heavily sheared carbonaceous slate near the Mahabharat Thrust (Stocklin and Bhattarai, 1981).

The movement of the Kathmandu Complex southward resulted in development of multiple deformational structures: four episodes of folding in the rocks of the Upper Nawakot Group and three in the Bhimphedi Group rocks (Kansakar, 1982). Folds and faults developed in the rocks are important features in modification of groundwater circulation.

About half of the watershed in the middle part is covered by mica schist interbedded with impure quartzite band in decreasing proportion towards the top. Gneissic intrusion confined to mica schist has penetrated splintery quartzite rock (Fig. 3). Except for resistant quartzite, schist and gneiss are decomposed. Phyllite covering about six percent of the area is located in the eastern part. Thick red soil is developed on relatively fast-weathering mica schist and phyllite. Red soil creates hydrological problem, its poor infiltration capacity adversely affect groundwater recharge, encourages rapid runoff along confined route which result in gully formation. Wider valley at the lower reaches of the Jhikhu Khola is developed on less competent schist and phyllite rocks. Carbonate beds including marble and limestone are important rocks in terms of base flow because they support natural springs year around. The general rock alignment is northwest-southeast with moderate to steep inclination to the southwest. From its confluence with the Sobarne Khola onwards, the Jhikhu Khola flows almost along the Mahabharat Thrust, the major structural unit in the study area.

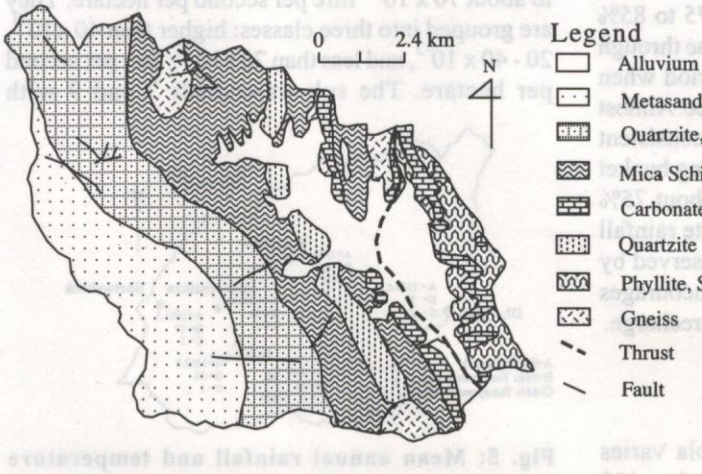

Fig. 3: Geology of the Jhikhu Khola watershed.

Distribution of major rocks when examined by sub-watersheds, showed three distinct patterns. In the first group carbonate rock occupies more than 40% of the sub-watershed area, for example, sub-watersheds 7, 9, 10, and 2. Second category includes sub-watersheds 15,16,18, and 17, which are dominated by sandstone, sharing more than 50% of the sub-watershed area. Finally, the third group consists primarily of schist with subordinate quartzite (more than 40% of sub-watershed area). Sub-watersheds 2, 18, and 12 belong to this group (Fig. 4).

Temperature and Rainfall

Rainfall is the main source of recharge to the aquifer that sustains the base flow within the watershed for entire year. To document the rainfall variations and temperature fluctuations, data from six meteorological stations were analysed. The absolute maximum and minimum temperatures recorded are 38°C in Panchkhal station (June 2,1995) and - 2° C in Dhulikhel station (January 1993, 1994), respectively (Fig. 5). Elevation influences the mean annual temperatures: 21°C at the lower elevation and 16° at higher elevation (Table 1). In the valley floor, the temperatures frequently exceeded 35° C from April through September while at the higher elevation rarely reached above 35° C (Carver, 1997). The higher temperature values at the valley floor

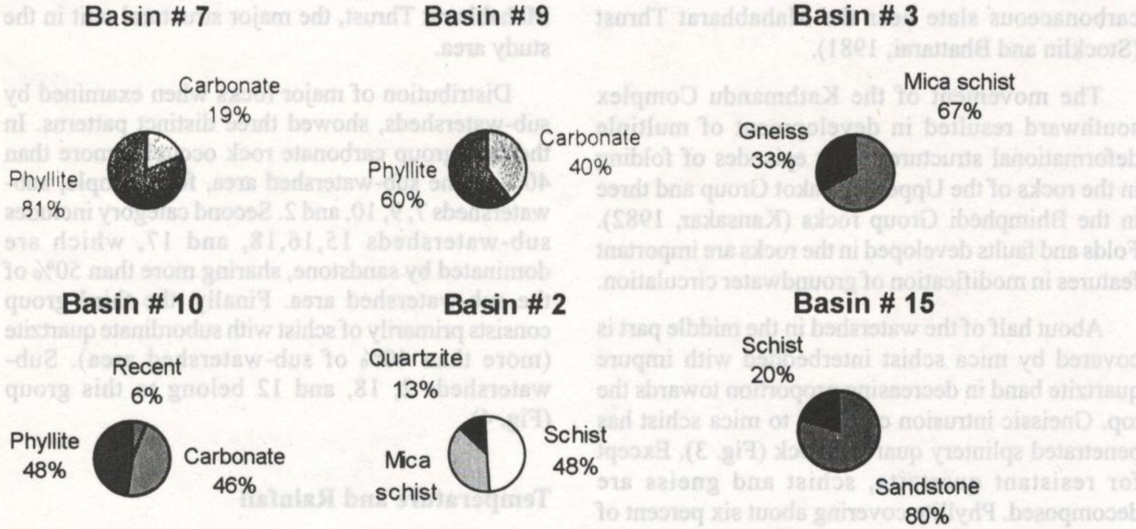

Fig. 4: Dominant rock types by subwatersheds (arranged according to decreasing specific discharge). Legend: Rct = ???, Sst = Sandstone, Sc = Schist, Qtz = Quartzite, Sch+Qtz = Schist and Quartzite, Car = Carbonates, Phy = Phyllite, Gns = Gneiss.

imply greater rate of evaporation loss compared to the higher elevation.

Table 2 shows the variation in average annual rainfall, which was well above 1300 mm at Dhulikhel (the north-facing slope) diminishes through 1200 mm at the valley floor to less than 1100 mm in Bhetwalthok (the south-facing slope). The south facing Hokse-Bhagawatisthan slope is generally drier through out the year compared to its north-facing counterpart.

Across all 24-hour gauging stations 75 to 85% of annual total rainfall occurred during June through September and this is very important period when significant groundwater recharge takes place. Almost all springs in the study are rejuvenated. A consistent pattern in all five gauges (automated tipping bucket type established within the study area): about 75% of storms having a maximum of 10-minute rainfall with intensity less than 30 mm/hr was observed by Carver (1997). Low intensity rainfall encourages infiltration leading to better groundwater recharge.

Stream Flow

Stream discharge of the Jhikhu Khola varies from few 0.01 m^3/s in dry season to more than 100 m^3/s during peak storm in the monsoon and remains few minutes depending upon the rainfall intensity and duration. The flow was measured at the outlet of each small basin in early June prior to onset of monsoon when the contribution of groundwater was significant and effect of surface runoff due to rainfall was almost absent. The drainage area of the sub-watersheds widely varies from 30 to 1300 ha (Table 3).

The measured values ranged between 0.7×10^{-3} to about 70×10^{-3} litre per second per hectare. They are grouped into three classes: higher than 40×10^{-3}, $20 - 40 \times 10^{-3}$, and less than 20×10^{-3}, litre per second per hectare. The sub-watersheds 7 and 9 with

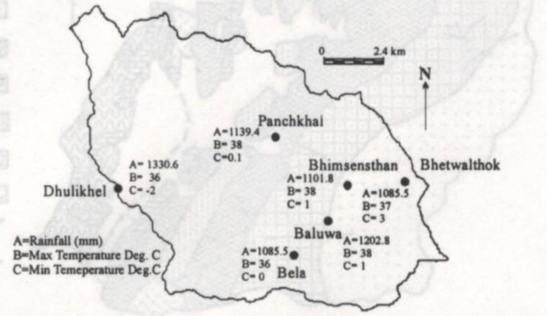

Fig. 5: Mean annual rainfall and temperature variation.

Table 1: Extreme and mean temperature values.

Station	Elevation	Daily mean	Absolute minimum (°C)							Absolute maximum (°C)						
	(m)	90-96	90	91	92	93	94	95	96	90	91	92	93	94	95	96
Higher elevation																
Dhulikhel	1560	16.9	1.5	1.5	2.5	-2	-2	0	2.2	29.5	30	31.5	29.5	31	34	36
Bel	1279	20.5	5	5	0.3	4	6	0	5	33.5	35	35	34	33	36	35
Bhetwaltho	1200	20.4				6	3	4	5				35	36	37	35
Lower elevation																
Panchkhal	850	21.2		2	2	1	1	0.1	2.2	35	35.6	35.5	35	37	38	36
Baluwa	830	21.2				1	1	1	3				36	38	37	38
Bhimsensthan	880	21.4				3	2	1	3				35	37	37.5	36.5

Table 2: Mean monthly rainfall values across six sites.

Site	Elev.	Average rainfall (mm)													Period
	(m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Of data
High elevation															
Dhulikhel	1560	20.2	22.1	23.9	26.6	106.9	232.4	368.2	322.9	155.4	26.0	22.0	4.0	1330.6	*1990-96*
Bela	1279	23.5	20.6	22.0	24.4	99.0	184.5	306.9	239.3	122.0	19.9	17.5	4.7	1084.5	*1990-96*
Bhetwalthok	1200	24.7	20.0	16.7	24.5	63.0	253.6	276.1	269.7	90.4	20.3	24.0	2.5	1085.5	*1993-96*
Low elevation															
Panchkhal	850	23.0	21.1	22.2	23.8	96.8	210.8	281.6	288.6	122.3	25.2	19.9	4.0	1139.4	*1990-96*
Baluwa	830	30.2	20.2	17.8	23.8	67.0	375.9	396.7	339.2	139.0	23.2	35.2	3.8	1202.8	*1993-96*
Bhimsensthan	880	32.6	19.7	15.6	20.5	68.1	278.0	261.5	271.3	82.9	21.3	27.9	2.5	1101.8	*1993-96*

Table 3: Surface area of individual basins.

Basin #	7	9	3	10	2	15	1	8	16	18	17	12	5	13	4	14	6	11
Area (ha)	68	30	125	54	463	439	957	136	674	1334	413	275	123	587	381	497	272	11141

relatively higher specific discharge rate are confined to south facing belt, which experiences low annual rainfall as mentioned earlier (Fig. 6). Again the sub-watersheds 2, 3, 10 with moderate flow rate are located in the drier south facing zone. On the other hand, sub-watersheds 1, 18, 17, 16, etc. generate low

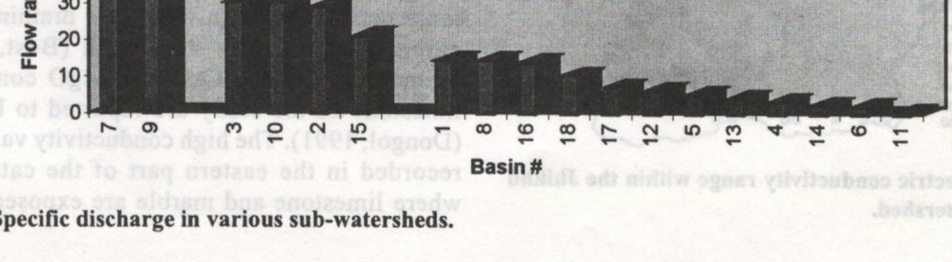

Fig. 6: Specific discharge in various sub-watersheds.

yield although they fall in higher rainfall zone. It implies that the rainfall directly does not control the base flow of the basins during dry period.

Stream Water Conductivity

The electric conductivity of the stream water was measured during low flow in dry period because it is the time of year, when the contribution of groundwater alone to the stream is the greatest. During dry season concentration of solutes in groundwater generally increases (Williams et al., 1990), because rainwater as dilutor is absent. The data obtained from some 100 sites ranged between 50 to 550 $\mu S\ cm^{-1}$ with the lowest reading of 52 $\mu S\ cm^{-1}$ near Charuwa to 568 $\mu S\ cm^{-1}$ at Kharanitar (Fig 7). A decreasing trend in the conductivity values is distinct from east to west. Three zones can be distinguished: a high range (> 300 $\mu S\ cm^{-1}$) in the eastern belt through moderate (100-300 $\mu S\ cm^{-1}$) in the central part to the low range (< 100 $\mu S\ cm^{-1}$) in the western belt of the study area.

DISCUSSION

Stream Flow versus Geology

The increment of the groundwater flow with increasing precipitation differs according to the geological factors (Mihalik and Kajan, 1990). Strong relationship between the tectonic lineaments and high discharge of springs are reported by Valdiya and Bartarya (1991). The interconnected fissures, pores, and solution cavities within the rock are important features for water circulation and storage (Klimentov 1983; Freeze and Cherry, 1979). In the study area, the carbonate terrain showed extreme character in terms of spring discharge. When the stream flow and geological material are examined closely sub-watershed by sub-watershed, it is evident that area containing large proportion of carbonate rock sustains higher base flow, such as sub-watersheds 7, 9, and 10. However, low flow is observed in the sub-watershed 6 with one third of area covered by carbonate rock. It is probably associated with the major thrust zone (Mahabharat Thrust) through which much of the water infiltrates. Generally, carbonate rocks are excellent aquifer that can store and gradually release substantial quantity of water (Green, 1965).

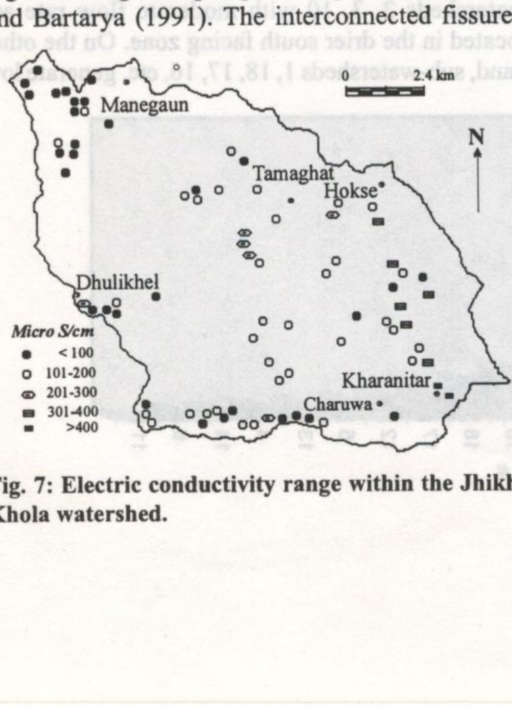

Fig. 7: Electric conductivity range within the Jhikhu Khola watershed.

Although sandstone is commonly known to be good aquifer, it ranked second in the watershed with specific flow ranging between 20 to 40 x 10^{-3} litre per second per hectare (Sub-watersheds 15 and 18). This can be attributed to the attitude of the bedding plane, which is dipping southwest. It may well be possible that groundwater is flowing on the other side of watershed towards the west.

Schist, the most dominant rock in the central part of the watershed is poor in water storage and discharge, but presence of fractured quartzite beds slightly improves spring's discharge from these areas. Sub-watersheds 5, 4, and 14 sharing large proportion of schist rock produce low flows.

The higher base flow from carbonate beds is followed by sandstone and least from schist and phyllite.

Geology versus Conductivity

The variations in rock types of the catchment with different dissolution rates affect the chemical characteristics of the drainage water. The total ionic concentration in the water draining from carbonate rocks are very high (Best, 1997; Klimentov, 1983). CaO and MgO content of limestone of the study are reported to be 42% (Dongol, 1991). The high conductivity values are recorded in the eastern part of the catchment where limestone and marble are exposed. Mica schist with subordinate quartzite and gneiss produced moderate values. Sandstone and quartzite are responsible for producing lower conductivity below 100 μS cm^{-1}.

CONCLUSIONS

Rainfall is the only source of groundwater recharge in the study area. Its intensity, duration and amount are important in aquifer recharge. The geological study indicated that there is a strong relationship between water conductivity and bedrock material: rocks rich in quartz being responsible for producing moderate flow and low conductivity water. In contrast, the metamorphic rocks particularly marble and limestone/dolomite produce more flows with significantly higher conductivity values. The stream conductivity values obtained during the dry season can thus be used as crude fingerprint technique to identify sources of groundwater in relation to bedrock formation in the watershed.

The study has provided a broad overview of groundwater sources and water quality in relation to bedrock type. What is needed now is to conduct a more detailed analysis of infiltration capacity and distribution of open spaces, such as fracture planes, fissures, joints, faults, etc in the rock mass. Some tracer studies will then be needed to determine flow pathways and rate of discharge from the rock formations.

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