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FEASIBILITY OF GROUND WATER DEVELOPMENT IN THE MOUNTAIN TERRAINS OF NEPAL - A CONCEPTUAL STUDY.

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ABSTRACT

The mountain terrain of Nepal, particularly the Midland zone, acquired importance in view of its inhabitation, its population and utility of the entire hill slopes for agriculture. However, water resource has become a problem both for domestic and agriculture purposes on these higher altitudes.

The Midland zone which is composed of meta-sediments and gneisses become water bearing by virtue of fracture porosity due to intensive tectonic episodes and partly due to weathering. Presence of numerous springs and seepages in this zone bears testimony of this.

Conventional vertical bore wells in this terrain would be a failure as the water table in the mountain aquifers is generally steep following the hill slopes. Alternately, horizontal bore wells are suggested for ground water development from these mountain aquifers, cautious development and suitabel methods of artificial recharge may qualify these aquifers as eternal reservoirs of ground water. Development of ground water from these hills may also reduce landslide hazards.

INTRODUCTION

Nepal is essentially a hilly country with about 83% of its total geographical area falling in this terrain. Leaving the Higher Himalayan region above an altitude of 5000 m which is occupied by perpetual snow, about 68% of the geographical area is occupied by the mountain or Midland region comprising the Mahabharat range and the Midland zone. About 62% of the population in the country reside in the Midland zone. Most of the hill slopes in this region are utilised for extensive cultivation with rainfed crops like maize, millet, corn, barley, potato, vegetables and fruits.

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Ground water development programmes in the country have been implemented initially in the Terai region which is underlain by alluvium forming promissing ground water potential zones. Ground water exploration in the hilly terrains is yet to be commenced, though minor pockets like Kathmandu valley have been thoroughly investigated for the city water supply. In view of the vast geographical area and dense population in the Midland mountain terrains of the country and the drinking water problems in many parts of this region, there is an imminent urgency and need to find out the ways and means of ground water development in this mountain terrain.

Climate

Nepal enjoys wide range of climatic conditions because of its characteristic topography. The country is divided into four climatic zones:-sub-tropical, temperate, alpine and arctic which are related to altitude. The Midland region falls mostly in the temperate zone with the average (1963-82) maximum and minimum temperatures at 32.6°c and 0.05°c in summer and winter respectively (recorded at Kathmandu).

Rainfall in the country also shows a wide range of its distribution from 250 mm or less in the inner Himalayan valleys to 5000 mm along the southern slopes of the Annapurna range in the western part. The Midland zone receives an average annual precipitation of 1000 mm in the eastern and far western parts, 2000 mm in the central part and 4500 mm in the western part. The average rainfall of the country is given as 1600-1800 mm by different authors. About 80% of the total precipitation is ensued between June and September.

Topography:

Nepal is topographically divided into six divisions-Terai, Churia Hills, Mahabharat Range, Midland, Great Himalayas and Trans-Himalayan Valleys, each having its characteristic topographic features. Except the Terai region, all other divisions belong to mountain terrain of the Himalayas.

Churia and Mahabharat hills possess steep slopes rising abruptly on their southern side. Slopes in general vary in inclination from about 30° to almost vertical. Southern slopes of these hills are considered to be practically dry with little moisture retaining capacity. These terrains are rugged in nature. High mountain land on the other hand is unsuitable for agriculture because of topographic and climatic conditions.

In contrast to the above hill ranges on the south and the Great Himalayas on the north, the Midland zone over a width of about 30 km, is relationly a low lying area with smooth tipography in general. The average altitude of this zone is about 2000 m. Almost all the mountain slopes in this land are carved in to step like terraces and developed with extensive cultivation. This zone receives its importance being thickly populated because of congenial conditions for inhabitation with suitable topography of the hills and climate.

Tectonic and river valleys form a subgroup in the mountain ranges which in some places, are very wide in aerial extent. Total area of these valleys is estimated to be 6000 sq.km and nearly 2800 sq.km of this is under sparse forest. Except river valleys and tectonic valleys like Kathmandu, Pokhara, Banepa, Panchkhal, Dang, Surkhet etc., very few areas are stated to be suitable for agriculture.

Soils:

Soil development ir the above topographic divisions is variable according to climate, lithology and topography. Climate is a dominent factor, Being cold in the Greater Himalayas, soil development is very poor. In the Churia hill, lithology plays a dominent role as they are composed of mainly younger sediments as sandstones and shales which are not prone to much of chemical weathering. The soil here is mostly sandy. Mahabharat range though is situated in a favourable climatic zone with suitable rock types as granites, soil development is poor on the higher altitudes because of topography i.e. their steep slopes and hence dominent physical weathering and erosion. Quartzites, which is another dominent rock type along with granite in this range, is resistant to weathering. Pebbly or gritty soils are therefore common in this range.

A well developed soil zone can be observed in the Midland zone with suitable climate, topography and rock types, favouring intensive chemical weathering. Since phyllite is the dominent rock type in this zone, soil development is considerable with lateritic or clayey nature. Quartzites and cherty dolomites are resistant to weathering while limestones give rise to calcareous soils. Granite is found to give rise to sandy soil. Muscovitisation is found to be the dominating initial weathering process of all the felsic and femic minerals in this area which may be followed by kaolinisation. This is one reason for the abundance of micaceous minerals in the soils and sediments of Himalayas.

River Systems:

Mountain rivers of Nepal are perennial with significant base flow in the lean period. The river hydrographas show peak discharge during monsoon i.e., between July and September which declines sharply by November and reaches low in February. It was eastimated to range from 25 to 98 cuses during these months in different rivers. The stream discharge between October and February is solely attributed to ground water contribution. A significant rise in the stream discharge is recorded from March to June which is maninly due to the snow melt in the upper reaches.

The characteristics of the river beds and river flows are distinct for each physiographic division of the country. River valleys in the Midland zone generally become wide compared to the Greater Himalayas with a change in their direction from N-S to E-W. Lithology of the river basin however plays a significant role on their size and shape. For instance river valleys are narrow in the areas underlain by hard rocks like dolomite, quartzite and granite and become wide in the phyllite and schistose rocks. Gradient of the river beds reduces as they enter Midland zone. This facilitates deposition of the sediment load considerably in this zone leading to meandering of the rivers and development of flood plains with a total width of more than 1. km in certain parts. River terraces are extended over a length of 4 to 6 km in some basins. Such flood plains are advantageously used for cultivation. However, frequent shifting of river channels are reported in such areas causing shifting of paddy fields on to either side.

The principal mountain rivers are parallel and infer their tectonic origin. Each bend in the river course also reflects a structural control.

GEOLOGY

Geologically, the Himalayas of Nepal depict longitudinal zoning from north to south. On the northern side, the Higher Himalayas are constituted mainly with crystalline rocks like gneisses and migmatites and Tethys sediments in certain areas. The Midland is comprised of mainly meta-sediments. Mahabharat range on the south is very distinct with igneous intrusions in the east and central Nepal but merges indistinctly with the Midland towards west. Quartzites, dolomites with phyllite at the base of the hill range are the other prominent rock types in this range. The Churia hills bordering the Teari plains comprise of Siwalik sedimentary formations which include fine to coarse-grained sandstones, boulders and shales and clay beds.

The Midland group of rocks which are of particular interest in the present study, are divided into four sub-groups based on lithologic characteristics as follows:

Upper sub-group	calcareous succession
Middle sub-group	siliceous succession
Lower sup-group	arenaceous succession
Lower most sub-group	argillaceous succession

The lower most sub-group is represented mostly by black slate which is considered to be intercalated with the lower sub-group. The lower sub-guoup mainly consists of medium to coarse-grained sandstone with alternate layers of phyllite. The middle sub-group contains thick ortho-quartzite layers which are associated with slate and phyllite in some areas and slate and limestone in a few specific areas. Phyllite and biotite-schist are associated with this formation in some places. The upper sub-group is characterised by the occurence of stromatolite limestone with some slate. Green phyllite and meta-sandstone are also intercalated.

Kathmandu group of rocks comprising mainly of limestones and sandstones occupy the Kathmandu basin.

Structure and Tectonics:

The Tethys Himalayan zone and the Midland zone are the two principal tectonic units of the Nepal Himalayas and the Mahabharat zone is an independent tectonic unit.

The Main Central Thrust zone is an important tectonic unit that seperates the Midland tectonic elements from the Higher Himalayas.

The Midland zone is defined as the intermediate area between the Main Central Thrust and the Mahabharat zone. This zone is composed of the Midland meta-sediments associated with a small amount of younger sediments. Its width is more than 100 km in the western part of Central Nepal but narrowing eastwards to less than 20 km in the Eastern Nepal. This zone is divided into three areas from east to west by Thaple and Jude faults between East and Central Nepal and Samea Thrusts I and II between Central and West Nepal. Threre are numerous longitudinal faults and less number of transverse faults in this zone. Some of the faults are associated with broad shear zones.

Major folded structures of this area are two anticlinorium and one synclinorium. Most of the rocks dip at high angle above 30 ° and generally at 60-80° due north.

As a result of these tectonic disturbances, the rock types in this zone are fractured and jointed with more than two sets at places and with varying intensities depending on the tectonic elements and their proximity to the disturbed zone.

GROUND WATER CONDITIONS

Ground water occurance in the Midland zone can be described with reference to the topographic location of the aquifers. The aqufers may be classified into (1). River valley aquifers (2). Tectonic and Dun valley aquifers and (3). Mountain aquifers.

River Valley Aquifers:

River terrace deposits or flood plain deposits wherever occur in considerable extent form potential aquifers as they are reported to contain boulder, gravel and sand layers intermittent with clay beds. As the rivers in this zone are perennial these deposits below the stream bed level remain saturated through-out the year and hence would become a dependable source of ground water without any safe yield restrictions. Exploration of these aquifers can be easily taken up with conventional electrical resistivity surveys.

Tectonic and Dun valley Aquifers:

Sedimentary deposits in the tectonic valleys like Kathmandu are of huge thickness and form both confined and unconfined aquifers. The Kathmandu valley has been throughly investigated for its hydrogeological potential and ground water development has been initiated. Similar detailed hydrogeological investigations would reveeal feasibility of ground water development in the other tectonic and Dun valleys also.

Mountain Aquifers:

Unlike the above two types of aquifers which are situated sub-surface, the mountain aquifers are 'aerial aquifers' or 'hanging aquifers' located in the mountains above the local ground level. Nature of these aquifers, water table configuration and its fluctuation potentiality of the aquifers, design of well structures, well hydraulics and quality of ground water are to be studied in great detail as these aquifers differ from the usual sub-surface aquifers in many respects.

Aquifer Setting: Crystalline rocks or meta-sediments form aquifers because of their secondary porosity due to weathering and fractures. Crystalline rocks like Sheopuri injection gneiss is intensely weathered on the surface along the hill slopes. Fractures and joints in the inner part of the hills beyond the weathered zone however remain open and become favourable sites for holding ground water. Weathered zone, which is of clayey nature possess relatively less permeability than the interior fracture zones, and act as an aquitard and hence as a sealing layer on the surface (Fig.1 b). Ground water therefore is trapped inside. It may flow out along the hill flanks in the form of seepages and springs only where the weathered zone is thin or absent as at places like gullies and ravines along the hill slopes. Crystalline rock hills therefore become very favourable mountain aquifers for ground water development.

Meta-sediments in the Midland zone are mainly represented by phyllites; and sandstones/quartzites and limestones/dolomites are frequently intercalated with them. These arenaceous and calcareous rocks wherever fractured form potential aquifers. The ground water potentiality of these aquifers depends on their disposition in relation to the phyllite beds. When a quartzite or limestone formation with high dip is sandwiched between two phyllite beds as shown in (fig.1.c), it becomes a vertically confined aquifer with its ground water protected from leakage along the hill slopes. But when these beds form hill flanks with phyllite at the centre or at the other flank (fig.1.d), certain amount of ground water from them is likely to be leaked out as seepage or spring. Phyllite is unlikely to form a potential aquirer because of its soft nature and relatively low permeability. However, limited quantities of ground water is likely to occur in these formations. When the entire hill is made up of quartzite or limestone, its ground water potential is similar to that of a gneissic rock but, however, there would be a greater leakage of grond water as weathered zone in these formations is generally negligible.

Water Table: Mountain aquifers may be generally treated as water table aquifers. Water table in gereral follows topography in the case of sub-surface aquifers. The same may be presumed even in the case of mountain aquifers as shown in fig.1.a. Water table fluctuation is also expected to be very high in these aquifers due to heavy seepage losses along the mountain slopes. A schematic pattern of pre-monsoon and post-monsoon water table configurations in different lithostratigraphic dispositions is shown in fig.1. The fluctuation may be reltively high in the more permeable formations as fractured quartzites and limstones in comparison to phyllites, topography remaining same. However when these formations are sandwiched between phyllite formations, the fluctuation may be relatively less as the ground water leakage is reduced.

The water table may be intercepted in some parts along the hill slopes resulting into a seepage or spring (fig.1.a) depending on the discharge. Springs are considered to be very few in the Midland zone and they are confined to fault zones in general if they are present. These springs emerge at mid-altitudes of the hills and in some instances about 150 to 300 m below from the peaks. Some springs are observed to emerge during August-September i.e during or after the monsoon period and reduce in discharge or vanish in the summer period. This confirms the presence of ground water in the mountains and seasonal fluctuation of water table in them.

However, an observation of springs in the Kathmandu-Kakani section reveals their occurence all along the highway from near foot hills to almost the peak level. These springs are of depression type i.e due to interception of water table in the mountain stream sections. High discharge springs are noticed in the limestones of the Nagarjun hill and again in the fractured Sheopuri gneisses. Very low discharge springs and seepages are located in the schistose (phyllite) formations. Such seepage zones are tapped by horizontal pipes utilising them for local domestic needs. On the terraces at the lower levels in the valley, even paddy is irrigated during March with standing water in the fields.

Ground Water Development:

Ground water from the valley aquifers can be exploited through tube wells. Ground water development from the river valley aquifers depends on the depth of the aquifers and distance from the present river courses. In the river terraces, away from the river courses and not affected by river shifting, ground water can be tapped through filter point wells or shallow tube wells. Collector wells and infiltration galleries may be the ideal structure in the flood plains where flood waters submerge these alluvial plains during monsoon season and when they are to be located in proximity to the river courses. These wells which can yield very high discharge may be best utilised for tapping the stream flow during lean periods also and as a means of lift irrigation for supplying water even to the places on higher elevations. These well structures can be constructed in the river terrace deposits depending on the hydrogeological setting.

The problems with ground water development in Nepal are with reference to the mountain aquifers. In this terrain, vertical bore wells or tube wells hardly pierce the aquifers as the water table also steeply dips parallel to the hill flank as shown in fig.1.a. The wells are to be drilled very deep if located on the peaks and in case of DTH (Down the Hole Hammering) or Percutsion rigs, the depth of water table may be beyond their reach i.e beyond 100m below the peak. High water table fluctuation, limited aquifer extent (truncated on slopes) at higher altitudes lead to higher drawdowns under pumping conditions resulting in low discharges. These bore wells may therefore become uneconomical. Bore wells drilled at the foot-hills may be in the safe zone of water table but in this case the water is to be lifted to the higher levels on to the mountain slopes for irrigation or drinking, as most of the irrigation and inhabitation in the Midland zone is on the entire flanks of the hills. Therefore, conventional vertical bore wells may be a failure or uneconomical and may not serve the purpose.

Horizontal Wells:

For ground water exploitation from the mountain aquifers, a horizontal well apears to be the most ideal structure (fig.1.a). These wells are known as 'Qanats' in the arid regions of south western Asia and north Africa. They are mainly constructed in alluvial sediments of peidmont zones at the foot hills and their presence date back to 3000 years. Discharge of such wells vary seasonally with water table fluctuations and seldom exceed 100 m^3 /hr. Horizontal well is not unknown to Nepal. Ground water is tapped in Kathmandu perhaps at seepage points by excavating shallow pits and converging the seepage flow through an ornamented sluice structure and naming them as 'Dhunge Dharas' (Plate-4). These Dhunge Dharas also show seasonal variation in their discharges due to water table fluctuation. Their discharges are however low because of their shallow postion on the ground surface and finer sediments at the surface. Generelly horizontal wells on sloping gound surfaces are suggested either at contact springs or dike springs. Ground water development through horizontal wells from a mountain may be the rarest experimentation in the world if implemented in Nepal by virtue of favourable hydrogeological setting and utilisation on the entire mountain slopes in the Midland zone.

Design of Wells: Horizontal bore holes can be drilled by rotary rigs or percussion rigs depending on the formation whether soft or hard. Blank pipes or perforated pipes or a combination of these two can be inserted in these holes to different lengths depending on the formation. In the hard rock formations, the bore hole may be left nacked in the interior part. It is suggested that these wells should have a downward slope into the aquifer to prevent formation of a vaccum inside the pipes. The well can be of small size varying in diameter from 2.5 to 7.5 cm and rarely 10 cm depending on the expected yield from the aquifers. Ground water through these wells can be obtained by gravitational flow which can be controlled by valves at the discharge ends. However, normal centrifugal pumps can also be fitted directly to the well using it as a suction pipe, where the aquifers are potential enough and where water supply is required in large quantities either for irrigation or drinking water supply. The average discharge of bore wells (vertical) in the hard rock aquifers is 1000 gph and a maximum of 2000 gph is common though rarely it goes up to 5000 gph. Usually this much of discharge can be extracted through 5.0 to 7.5 cm diameter wells. For drinking water supply to small villages or settlements, wells of 2.5 cm diameter may meet the requirement. Discharge of these horizontal wells gradualy increases with their position from peak down to the foot hill (fig 1.a) permeability of the aquifer remaining same. This is in accordance with the simple hydraulic principle-presuming the entire hill as a vertical body of ground water, discharge increases with depth due to increase in hydrostatic pressure (fig.1.a).

As shown in fig 1.a, the wells should be located below the lowest level of water table fluctuation i.e below the pre-monsoon level. If it is located above the post monsoon water table, the well turns out to be a failure or dry. When they are located in the zone of water table fluctuation, the wells become seasonal with their discharges highly variable with change in water table elevation and finally becomes dry during pre-monsoon period. The wells located below the permanent water table position become perennial. Even in their case, the fluctuation of water table which results in a change of hydrostatic pressure in the aquifer would exert marginal difference on their yeilds but become negligible towards the foothill.

Horizontal wells along the hill flanks therefore provide ground water supply on the entire hill slopes from near peak levels to the foot hills. The ground water from these wells can be taken through pipes or channels to different terraces following contours by gravitational flow depending on the discharge. This practice would become very economical for terrace irrigation.

Management of ground Water:

Management of ground water reservoirs form a prime factor in the ground water development of an area. The basic aspect of management is to find out safe yield or perennial yield of the aquifers and its safegaurd. There are different methods of arriving at this factor like water balance method, water budgetting, water table fluctuation method etc. The mountain aquifers are aerial and do not fall in any specific drainage basin. In fact, they occupy the drainage divides. The perennial yield can therefore be estimated only by the annual water table fluctuation method as the other methods are applicabel generally to the ground water basins.

Water table fluctuation in the mountain aquifers can be determined by constructing horizontal peizometers similar to the horizontal wells at different elevations of the hills. An approximate estimate of specific yield factor as given by Sharma, (1974) taking into consideration the areas of the drainge basins and the base flows in the respective rivers, shows 9 to 23%. These figures fairly agree with the nature of formations. However, a detailed study for each hill would reveal more realistic figures at macro-level.

The annual water table fluctuation in the mountain aquifers is mainly due to leakage through seepages and springs as there is no ground water development at present. This is evident from the base flow during the lean period in different rivers varying from 775 to 3038 km^3. The minimum flow of river waters as a contribution from ground water in the month of February varies from 25 Cumecs in the Kali River to 98 Cumecs in the Karnali River.

It is apparent that ground water development from the mountain aquifers may lower the water table further down and finally dewater the entire hill section. However, it may be argued that construction of horizontal wells would only divert the otherwise leakage water through these structures and reduce general leakage in other directions. However, these wells may cause some additional draining of the aquifers but the safe yield factor may be determined in the changed situation.

Artificial Recharge:

To meet the additional draft through the wells from the mountain aquifers, some measures of artificial recharge may be considered. Though, the general techniques of surface water spreading are not feasible for these aquifers, recharge well method may be adopted. Vertical bore holes of 10 to 15 cm diameter may be drilled across the mountains at different elevations down to the water table position, only along the water coursed i.e Ist and IInd order mountain streams. This would allow the running water (during monsoon period) to infiltrate down and to build up the water table. Construction of check dams across such drainage courses and afforestation along those courses would help in reducing the velocity of running waters along the mountain slopes and increase the ground water recharge.

Other Advantages:

Ground water development in the mountains, apart from meeting the drinking and irrigation needs of the people, would protect topography and excessive soil erosion.

Ground water plays an important role in the landslides and soil creep in the mountain slopes. It increases the effective weight of the material that is saturated, lubricates the sliding planes and tends to weaken many materials. More significant is the fact that it develops hydrostatic pressure between the weathered zone and the fractured zones behind it, which finally push the soil zone down slope either in the form of soil creep or landslide. This is a common sight on many mountain slopes of the Himalayas.

Horizontal drains (horizontal wells in this case) in the hill slopes facilitate good drainage of ground water and releases hydrostatic pressure. This enhances the slope stability and reduces excessive soil erosion.

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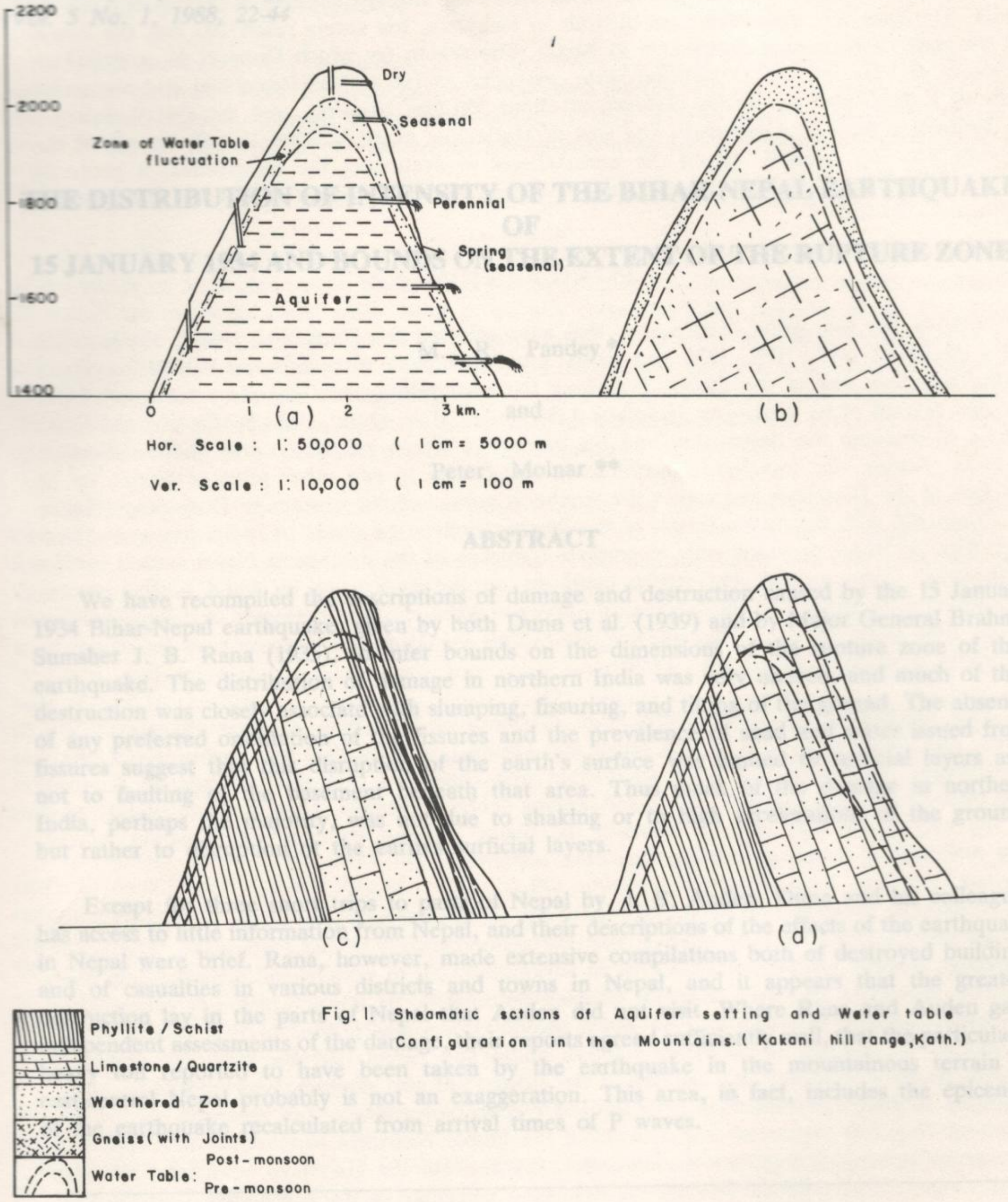

Fig. 1 Sheomatic actions of Aquifer setting and Water table Configuration in the Mountains. (Kakani hill range, Kath.)