Journal of Nepal Geological Society, 2002, Vol. 27 (Special Issue), pp. 151-158

Engineering and environmental geological investigations in Butwal area

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ABSTRACT

The Butwal town lies at the junction of the Siddhartha and Mahendra highways. It is endangered by landslides and floods every year during the monsoon season.

The area consists of the Tertiary sedimentary rocks (Siwaliks) in the north and Quaternary sediments (Terai Plain) in the south. The Main Frontal Thrust (MFT) marking the contact between the Siwaliks and Terai runs along the topographic break, north of the main settlement of Butwal.

Landslide at Jyotinagar (north of Butwal) triggered after the heavy monsoon of 27th August 1998 is considered as one of the main geo-hazard in the area. Wide–open cracks are marked around the crown of the slide with the slope of 40–60 degrees. Infiltration and percolation of water through these cracks is further aggravating the situation.

Engineering and environmental geological investigations were carried out in the area with an objective to prepare the engineering and environmental geological map at 1:15,000 scale. This map would be a great help to engineers, urban planners and decision–makers particularly in urban planning, landuse planning, infrastructure development, hazard mitigation, sustainable utilization of natural resources and environmental management. The types of information included in the map are lithological description of rocks and sediments, geo-hazards, mineral resources, features of environmental significance, riverbed mining, land fill site, landuse and urban geology.

INTRODUCTION

The area of field investigation covers over 100 km^2 lying in the latitudes between 27^0 39.5' to 27^0 43.2' N and longitudes between 83^0 23' to 83^0 29.5' E. It lies partly in Rupandehi and Palpa districts.

Butwal town lies in a very precarious location endangered by landslides in the south facing Churia hills, and floods in Tinau Khola every year during monsoon season. There is lack of urban level planning data in the field of Quaternary geology, land use and soil types.

Urban geology and landuse study were mainly focused on the Butwal municipality. Butwal town is situated within the Bhabar zone represented by coarse gravels, sand and silt. Immediately to the north of municipality extend fragile Siwalik foothills consisting of sandstone and shale.

The Main Frontal Thrust (MFT) marking the contact between the Siwaliks (Tertiary molasse type sediments deposited during the rising of the Himalaya) in the north and the northern marginal part of the Indo–Gangetic Plain (Terai) in the south. It runs along the break of the slope (Fig. 1) little north of main settlement area of Butwal. The main township is developed in the eastern bank of the Tinau Khola and consists of the Quaternary sediments deposited by the same khola. The main drainage, Tinau Khola originates from the Middle Mountains (Mahabharat Range) is not only responsible for carving the geomorphology of Butwal but also creates havoc frequently by flooding during heavy rainfall in monsoon season. Butwal town has good linkage with other urban areas of the country through the Mahendra (E–W) and Siddhartha (N–S) highways.

OBJECTIVES

Butwal municipality made request to Environmental Geology Project (EGP) of Department of Mines and Geology (DMG) to carry out urban geological mapping of the area with a view to prepare an engineering and environmental geological map required for the municipality for its urban planning, landuse planning and infrastructure development planning. Subsequently, present program was formulated by DMG with the following objectives:

Preparation of Engineering and Environmental Geological Map consisting information on present landuse pattern, natural and man-induced hazards, settlements, waste disposal sites, probable landfill sites, site for infrastructure development, etc.

PHYSIOGRAPHY AND CLIMATE

The study area includes partly mountainous area in the northern part and the plain area in the southern side. The Tinau Khola makes a V–shaped gorge southwards from Dobhan (confluence of Dobhan Khola and Tinau Khola) until the khola makes its way out into the plain in Butwal.

About 5 km part of the Siddhartha Highway passes through this section where there is frequent rock/block fall hazard.

The climate of the area is sub–tropical to tropical with hot and humid monsoon type summer followed by cool and fairly dry winter. Monsoon rainfall occurs during the months of June to September. Cool wind blows at night in the winter season (November to February) along the Tinau valley from north to south.

METHODOLOGY

Desk study, field investigation, laboratory study were supported by GIS analysis in the course of preparation of the engineering and environmental geological map. LANDSAT TM Scenes at 1:125,000 scale taken on 26th November, 1990 and aerial photographs at 1:15,000 scale taken in January, 1999 were studied and interpretated. Lineaments were marked in the TM–Scene that oriented mainly in N–S, NW–SE and NE–SW directions. These lineaments could be the deep-seated faults or fracture zones. IRS PAN/LISS Indian satellite data of the area at 1:15,000 scale (taken in January, 2000) obtained after the field work were very useful in incorporating the latest changing information in the map. Topographic maps (at 1:25,000 scale of 1993) of the investigated area were also acquired. The digital database of topographic map received from Topographical Survey Branch had been useful to prepare the base map of the area at 1:15,000 scale. Aerial photographs and base maps of the same scale made were useful for field work as well as in transferring the data from the air photo to the base map.

Field investigation was carried out in the dry season of 1999. It was planned with an aim to verify the interpreted information (like lineaments) in the field as well as compared with the previously identified thrusts, faults, lithological formations, boundaries, landuse and the infrastructures. Field survey enabled to delineate the potential areas of instabilities on the ground (hill slopes, river banks) that endangered the settlements (built up area) in Butwal. Attitude of the bedrocks and hill slopes were compared to establish the comprehensive bedrock geology and nature of the overlying soils. This type of work together with that in the valley floor areas help to furnish the Quaternary Geology.

A part of the present area was also investigated by Resistivity Survey in connection with delineation of suitable site for land fill development.

Standard Penetration Test (SPT) and augering was simultaneously carried out in the same area by a team of engineering geologists.

Laboratory tests and analysis of samples collected from the field were carried out in chemical and geotechnical laboratories of the Department of Mines and Geology (DMG).

GIS analysis was carried out at the Remote Sensing Section (RSS) of DMG using ARC/INFO software. The process includes the digitizing of the map, input of data and its storage, data processing and plotting of the engineering and environmental geological data.

APPLICABILITY AND LIMITATIONS OF THE MAP

The map is expected to deliver the basic geo-scientific information that are necessary for the planners, decision–makers, engineers, civil technicians and other users for landuse planning, urban and regional development planning, disaster mitigation and environment management. General information about present status of landuse, settlement areas, industrial area, ground condition, potential areas for mining, construction materials, ground water extraction, waste disposal sites, degraded and hazardous areas as well as other areas requiring protection measures are indicated in the map (Fig. 1). The map contains information on engineering and environmental geology like engineering properties of the rocks and soil, hazardous areas, natural resources, urban settlements, infrastructures and environmental issues. However, the detailed site investigation is always an essential aspect to be considered for specific engineering design and construction projects.

INVESTIGATION RESULTS

The study area (Butwal Municipality and the surroundings) covers partly on the Siwalik foothills and partly the alluvial plain of the Tinau and Dano kholas and their tributaries. The area is surrounded by the Siwalik Hill on the north, east and west.

GEOLOGICAL SETTINGS

Bedrock Geology

The Siwalik foot hills comprises of thick piles of fresh water molasse sediments deposited during Middle Miocene to Lower Pleistocene time and later uplifted during the rising of the Himalaya. The Siwalik rock sequence consists of colourful fine sandstone, shale and mudstone in lower part, medium- to coarse-grained sandstone and mudstone in the middle part and coarse sandstone and conglomerate in the upper part (Deb. Fl.Haz. Inv. 1999; Duvadi 1997; Duvadi et al. 2001; Rimal et al. 2001; Sikrikar and Piya 2001; Shrestha 1986).

The Lower Siwalik Formation (ls) is represented by fine- to medium-grained, hard, light–grey sandstone alternating with colourful mudstone, siltstone and shale. Predominance of mudstone over sandstone is generally observed. Cyclic sedimentation with fining upward sequence is often marked. Approximate thickness of the Lower Siwalik is 2,100 m. It shows smooth ridges and landslides are possible on steep slopes.

The Middle Siwalik Formation is divided into two parts: Lower Middle Siwalik Formation (ms1) and Upper Middle Siwalik Formation (ms2).

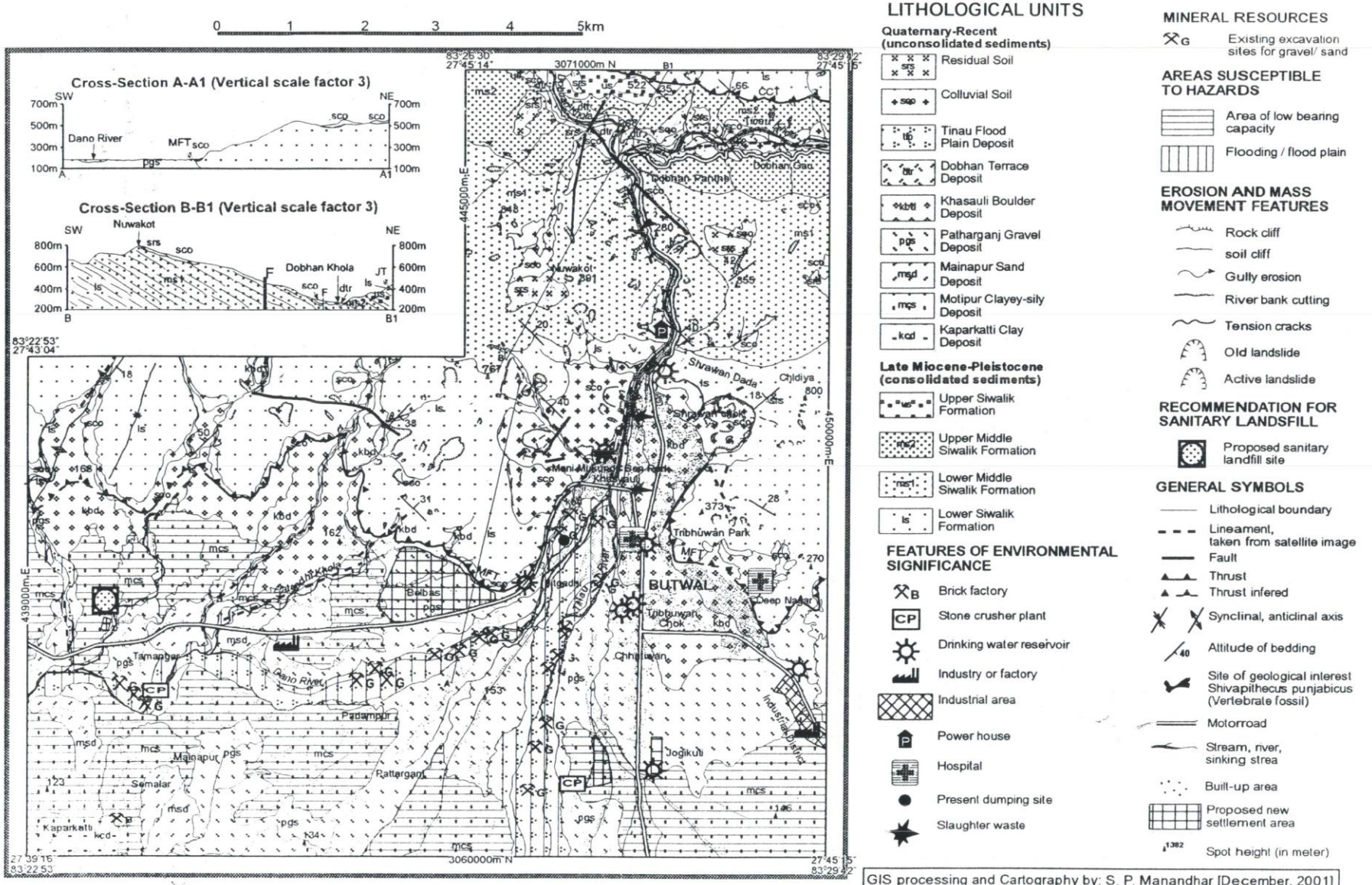

Fig. 1: Engineering and environmental geological map of Butwal area.

Lower Middle Siwalik Formation (ms1) is medium- to coarse-grained, thick-bedded, grey sandstone alternating with purple, yellow and grey mudstone, calcareous siltstone and grey shale (with plant fossil). Dominance of sandstone over mudstone is observed. *Shivapithecus punjabicus* (hominoid vertebrate fossil) is recovered near the intake of the Tinau Hydro Power (West et al. 1983 and 1991). The thickness of ms1 is approximately 1,200 m. Steep cliff formation, differential erosion forming scarp ridges and blockfall are common. Stabilisation measures to control blockfall are needed.

Upper Middle Siwalik Formation (ms2) on the other hand is gravelly/pebbly, coarse–grained, *pepper and salt* sandstone and vari-coloured mudstone. Predominance of sandstone over mudstone is observed. Approximate thickness is 700 m. The ms2 has high potential for badland development. Slope failure on riverbanks is common and erosion of incompetent rocks result into toppling of competent rocks. Reforestation in barren land is necessary.

The Upper Siwalik Formation (us) contains slightly consolidated conglomerate alternating with coarse, brown sandstone and grey or yellow brown mudstone beds. In the area it is developed only in the north of Tinau Khola and Dobhan Khola confluence. It has an approximate thickness of 300 m. It also has tendency of slope failure on riverbanks and high potential for badland formation. It is a good source of filling material. Reforestation in barren lands should be carried out.

In general the Siwalik rocks show a gentle to steep dipping towards north, northeast and northwest. Repetition of the Siwalik rocks sequence occurs due to the Central Churia Thrust (CCT). The Siwalik Group (Sub Himalaya) is separated by the Main Boundary Thrust (MBT) in the north and by the Himalayan Frontal Thrust (HFT) or Main Frontal Thrust (MFT) in the south (Duvadi 1997). The rocks of Lower Siwalik overriding the boulder beds of Recent alluvium along Rajpur Khola Section (west of Butwal) marks the exposure of MFT indicating Neo-tectonic activity in the area (Duvadi 1997; Shrestha 1986).

Quaternary Geology

The valley floor in the area consists of the sediments deposited by the streams mainly derived from the Siwalik hills and also from Middle Mountains. Mainly the alluvial soils of Quaternary–Recent are deposited on the plain and along the river valleys (by fluvial action). Colluvial and residual soils are deposited on the hill slope and elevated terraces as well as flat spaces on the hills. The valley floor sediments in the area are divided into nine units:

Residual Soil (srs),
Colluvial Soil (sco),
Tinau Flood Plain Deposit (tfp),
Dobhan Terrace Deposit (dtr),
Khasauli Boulder Deposit (kbd),
Patharganj Gravel Deposit (pgs),
Mainapur Sand Deposit (msd),
Motipur Clayey Silt Deposit (mcs) and
Kaparkatti Clay Deposit (kcd).

Residual Soil (srs)

This is developed on the areas along the flat to gentle hill slopes in Nuwakot and Gadda villages. It generally represents clay, silt and gravel of thickness 1-3 m. It has soft to medium consistency with mass movements likely on slopes near gullies. It is suitable for vegetation and dry cultivation. However, construction works on such slopes need protective measures.

Colluvial Soil (sco)

They are the inhomogeneous deposits at the foot of slopes and on gentle to moderate slopes. The thickness varies from 1-10 m and consists of clay, silt and sand with sub-angular gravel to boulder at places. It (sco) is loose to slightly dense where reactivation of mass movement is possible. It has high permeability with potential for groundwater recharge. In this area any type of excavation initiates slope instability and construction work requires proper preventive measures. sco is suitable for vegetation.

Tinau Flood Plain Deposit (tfp)

It occurs all along the riversides and on the flood plain. It has alluvial loose sediments consisting of boulder, cobble, gravel mainly of quartzite, sandstone, limestone/dolomite, with sand and silt. When mixed with clay it gives rise to the fertile top fine soil usable for the cultivation. The aggregates derived and deposited by the river often provide an excellent source of building and construction materials. Twelve river sections were studied in the area. It has low bearing capacity with loose density and high permeability. It is recommended to mine construction material as per the renewal by the river. No mining closer than 500 m from bridge sites and 50 m from riverbanks should be carried out. The tfp is potential zone for groundwater recharge and is thereby not suitable for waste disposal.

Dobhan Terrace Deposit (dtr)

This deposit is locally developed in Dobhan area (around confluence of Tinau and Dobhan Kholas) and is characterized by unsorted loose gravel mixed with sand and clay. It shows moderate bearing capacity with high permeability and is suitable for agriculture but not for waste disposal.

Khasauli Boulder Deposit (kbd)

This deposit consists of an angular to sub-rounded boulders mainly of calcareous sandstone intermixed with fine sediments covered by less than 1 m thick clayey silt. It (kbd) has moderate bearing capacity and medium density with slope failure on riverbanks and is suitable land for residential building construction. It is high recharge zone for groundwater and is the potential source of boulders for construction.

Patharganj Gravel / Deposit (pgs)

It has dominantly gravel and sand with clayey to sandy silt layer, which is less than 1 m thick on the top. It has high bearing capacity and hence it is the sound ground for building construction. It is the potential area for groundwater recharges and hence sewerage system needs proper lining to protect from groundwater pollution.

Mainapur Sand Deposit (msd)

This unit mainly have medium- to coarse-grained brown-grey sand covered by clayey silt layer less than 1 m in thickness. It (msd) has moderate bearing capacity and loose density and is locally susceptible to liquefaction. It is the potential area for sand mining and the heavy construction needs detail site investigation.

Motipur Clayey Silt Deposit (mcs)

This is brown-grey to yellow clayey silt and silty clay with fine calcareous concretions at places. It is generally underlain by gravel in Semlar area and stiff clay in Tamnagar area. It has the thickness of 2 to 6 m. It (mcs) has very low to low bearing capacity up to 3 m depth and slightly high bearing capacity at depth (below 3 m). It has low permeability and locally susceptible to liquefaction. The mcs is the fertile land for agriculture and it could be the potential area for waste disposal. Ground settlement is likely in this area and hence heavy construction needs deep foundation.

Kaparkatti Clay Deposit (kcd)

It has predominantly brown clay with subordinate silt having thickness more than 5 m. It has low bearing capacity, soft consistency, high plasticity and low permeability. It is the fertile land and suitable for wet and dry cultivation. It is also a potential source of clay. It could be a good geological barrier for leachate from waste disposal.

Resistivity Survey

Resistivity Survey of the Quaternary Sediments in the study area was carried out by using ABEM Terrameter to delineate the soil layers and find out the thickness of each clay and sand layers. This instrument consists of V-box and G-box. Potential electrodes and current elęctrodes were connected with V-box and G-box, respectively. Resistivity method is based on the measurement of electrical resistivity of earth-materials and involves the introduction of electric current into the ground and measurement of material's resistance to the current. By this method, controlled electrical current is introduced into the earth material through current electrodes. The resistance of the material to the current is measured by potential difference between two potential electrodes placed within the field created by current electrodes.

Preliminary analysis of 7 Soundings performed at Tamnagar shows more than 6 m thick layer. Main objective of the electric resistivity survey was to estimate the thickness of sandy and clayey layers. Other 6 Soundings were carried out with even–distribution at different locations in the study area to explore the subsurface geology in general. Preliminary qualitative analysis of these 6 Soundings shows rather deep groundwater level (more than 40 m) in the vicinity of the Siwalik (Churia) foothill indicating the area as a potential recharge zone. Soundings carried out in the south of Dano Khola show shallow groundwater level (less than 10 m).

GEOLOGICAL HAZARDS AND ENVIRONMENTAL DEGRADATION

Areas susceptible to landslides, rock/block falls, mass movements, debris flow have been marked in the map. Many places in Lower, Lower Middle and Upper Middle Siwalik rocks have been encountered with a number of tension cracks, active and old landslides in this area. Recommendations are made to overcome the possible risks caused by each type of hazards before any civil construction work is planned and implemented.

The valley floor sediments are classified according to their composition, degree of compaction and segmentation and the types of cementing material based on the Unified Soil Classification System.

Low Bearing Capacity Areas

Low Bearing Capacity Areas are found to correspond with Motipur Clayey Silt (mcs). It has very low to low bearing capacity up to 3 m depth with N–values less than 4. Slightly dense layers with high bearing capacity exits at depth below 3 m. It has low permeability and is locally susceptible to liquefaction.

Flood Prone Areas

Low lands adjacent to the Tinau, Dano, Satgadhi, Baurba, Rajpur, Suili, Dobhan and other streams in the area are likely to be affected by floods as they are prone to flood hazards. Hence, these areas are not suitable for human settlements but can be utilized for agricultural field. A risk of flash flood can always be a threat in these areas in the future.

Landslide, Erosion and Flood Hazards

Various small as well as large, active, old and dormant landslide are marked in the area along the hillside slopes. The Shrawan Dada (Jyotinagar) landslide (of 27th August 1998) on the south facing hill slope is considered to be one of the main geo–hazard in Butwal Municipality at the moment (Debr. Fl. Haz. Inv. 1999). Wide-open cracks are marked on the crown part of the landslides. The dip angle of the slope (40^0–60^0) is unstable and can create further sliding. In addition to these, areas with gully erosion and tension cracks are marked on the map.

Soil erosion and rock fall are also quite common in the hill slope area because of soft and fast weathering nature of rock/soil, deforestation as well as haphazard exploitation of construction materials. Area between Chidiya Khola and Dobhan village along the Siddhartha

Highway is very much likely to suffer from rock / block fall and soil erosion as well as landslides due to steep slope. High density of joint and differential erosion between soft mudstones and hard sandstones of the Middle Siwalik are promoting to the rock blocks to be detached creating landslide and block fall hazards. River bank cutting in Tinau Khola and Dano Khola is another threat that needs to be taken care of. This low land area that flooded during heavy rain is covered with sediment deposited by the streams are left barren during the dry season. These areas are suitable for both dry and wet cultivation but not for the construction of buildings. These areas have high ground water potential. The area should be avoided for dumping of chemicals and petroleum, municipal, industrial and hospital wastes.

Industrial, construction material and mining hazards

Industrial district and other industries like brick factories, stone crushing plants located near the settlements and the river banks could create health hazards. Several locations of construction materials quarry sites are seen in Dano and Tinau khola sides operated in haphazard manner. Improper mining of the construction materials have helped to trigger of the landslides and river bank scouring.

NATURAL RESOURCES

Surface as well as groundwater, non-metallic minerals like building stones and natural forests are the main natural resources, one can count on in Butwal area. Proper management and utilisation of these resources for the livelihood of the people are highly desirable.

Surface and groundwater resources

Tinau Khola originating from the Middle Mountains is the only river that has water throughout the year. Other streams originated from the Siwaliks have very less amount of water or not at all during the dry season. As far as the ground water is concerned, the level is very deep near the foothills of Siwaliks (more than 40 m) whereas it is less than 10 m further south of Dano Khola.

Mineral resources

The area does not have any potential economic metallic mineral resources. However, the non–metallic minerals resources like construction materials e.g. building stones, sands, gravels, boulders, cobbles and pebbles are abundant along the river beds of Tinau, Dano and other kholas. Proper and planned–mining of these resources is needed urgently.

Reserve forests

Most of the hilly sides in the area are covered by the forests like protected and community forests. Reserve forests are also seen in the plain area near army and police camps (southeast side of the area).

LANDUSE

Existing landuse pattern in the area are agricultural, lands, forests, settlements, industrial, recreation centers, infrastructures and land fill/waste disposal sites.

Agricultural and forest lands

Most of the flat, low lands in the plain in the south are suitable for wet cultivation like paddy (rice) crops. Low angle sloping lands are good for dry cultivation like maize, millet, wheat and cereals. Forestlands are mostly in the hilly sides. Different types of forests like open forest, scrub, orchard, nursery and protected forest are categorized in the area.

Urban settlement and industrial areas

Urban settlement (existing, planned, proposed and expanded) areas are marked in the map. Proper sewerage system in Butwal township is inadequate. Sukha Nagar, Deep Nagar, Naya Gau, Belbas and Tamnagar need urgent management of the drainages. The crucial area of manmade pollution is located in the west of Tinau Bridge of East–West Highway near Mani Mukund Sen Park area. Squatter's settlements near the east bank of Tinau Khola (west of Chhatiwan) as well as in the island south of Tinau Highway Bridge (north of Jitgadhi) located in the flood plain between Tinau and Dano kholas are the alarming threat of encroachment of the riverbanks and flood plain.

Recreation centers and open spaces

Mani Mukund Sen Park and Municipality Park are the only two existing public parks in the area. Siddha Baba temple north of Butwal along the Siddhartha Highway is also recently developed as a park and the temple area is renovated and developed for religious purposes keeping the religious and cultural values. Open spaces of Campus playground, army and police training ground are marked on the map. These places are important for relief operations during natural calamities like floods, landslides, earthquake and other emergency times.

Landfill/waste disposal sites

Butwal municipality is lacking its own permanent, sanitary landfill site to manage the safe disposal of its solid waste produced from the urban settlement and industries. At present, Butwal municipality with population of 80,000 is temporarily dumping daily wastes (around 6–8 tons) into the Tinau flood plain without taking any consideration about its environmental impact. On request of Butwal municipality DMG has carried out first, preliminary assessment and later fairly detail "Investigation of Subsurface Geology/Soil Condition of the proposed Tamnagar Sanitary Landfill Site" (Duvadi et al. 2000). The site has been found reasonably suitable for land fill site development despite relatively low values of Cation Exchange Capacity (CEC).

GEO–ENVIRONMENT AND POLLUTION

Water pollution, groundwater pollution, air pollution and noise pollution

Direct connection of sewage drainage to Tinau Khola, haphazard disposal of industrial and hospital waste in the open space and streams, and improper dumping of solid wastes into the riverside are the root causes of river water pollution. Expansion of urban area without adequate infrastructures is another major cause of the environment pollution. Increasing vehicular traffic with their pressure horns, music with loud speakers from the local vendors causes the noise pollution whereas the operation of old vehicles with low quality fuels, industry's chimneys and increasing volume of garbage and industrial waste cause the air pollution. Analyses of river water, groundwater and tap water from different locations show fairly high coliform content in riverwater and low in ground water. Sewerage water samples from four different localities are highly polluted biologically but heavy metal content is negligible (Kaphle 2000).

CONCLUSIONS

Butwal municipality is situated on the alluvial plain of the Tinau and Dano kholas and their tributaries and consist of Sub–Recent to Recent sediments. The Butwal town is endangered by landslides and floods every year during the monsoon season. Landslide at Jyotinagar and riverbank cutting in Tinau and Dano khola is severe.

The area consists of the Tertiary sedimentary rocks (Siwaliks) in the north comprising the thick piles of fresh water molasses, sediments and Quaternary sediments (Terai Plain) or the valley floor sediments in the south deposited by the streams mainly derived from the Siwalik hills and also from Middle Mountains.

The Main Frontal Thrust (MFT) marks the contact between the Siwaliks and Terai that runs along the break of the slope north of the main settlement of Butwal. Four fold divisions for the Siwaliks (Lower, Lower Middle, Upper Middle and Upper) is applicable to the area while the valley floor sediments are divided into nine units. In general the Siwalik rocks show a gentle to steep dipping towards north, northeast and northwest.

Preliminary Resistivity Survey (Soundings) of Quaternary Sediments shows the deep groundwater level (more than 40 m) at the vicinity of the Siwalik foothill (indicating the recharge zone) and shallow groundwater level (less than 10 m) south of Dano Khola.

Flood Plain Deposits often provide an excellent source of building and construction materials. Proper drainage system in Butwal municipality area is inadequate. Also the squatter settlements in Tinau–Dano flood plain is an alarming threat. The proposed site in Tamnagar is suitable for sanitary landfill development. Direct connections of sewage drainage into the Tinau Khola have caused the pollution of riverwater.

The map would be a help to urban planners and decision makers at local level particularly in hazard mitigation, sustainable utilization of natural resources and environmental management. Information included in the map are lithological description of both hard and soft rocks (Quaternary sediments), geo-hazards (natural and man-made, erosion, block fall and mass movements), mineral resources, features of environmental significance (water and air pollution), river bed mining, land fill site, landuse (forest) and urban geology.

ACKNOWLEDGEMENTS

The authors express their sincere gratitude to Mr. N.R. Sthapit, Director General and other managerial authority of the Department of Mines and Geology (DMG) for the permission to publish this paper.

Thanks are due to Dr. R.P. Bashyal, DDG; Mr. B.M. Jnawali, Co-ordinator, Environmental Geology Project (EGP) and Mr. K.P. Kaphle, Sr. Div. Geologist for their fruitful discussion, valuable comments and necessary helps during the field works as well as the preparation of the map and report.

The authors are obliged to Dr. K. Busch, Team Leader, EGP, BGR Germany; for making valuable comments on the map.

The authors are highly thankful to Mr. S.P. Manandhar, Geologist for his help in preparing the map using GIS techniques.

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