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Natural hazards and environmental geological assessment of the Pokhara Valley, Western Nepal

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ABSTRACT

Pokhara Valley is an intramontane basin situated on the lap of southern foothills of Annapurna and Machhapuchhre Himal. The valley is surrounded by hills, which are mainly represented by low to medium grade metamorphic rocks. It is believed that the valley fill sediments were derived from far north in the Himalaya, during three different catastrophic debris flow events along Seti River in Upper Pleistocene to Holocene Epoch. These sediments are rich in calcareous constituents and are susceptible to sinkhole and land subsidence hazards.

Karstification is widespread in the form of sinkholes, caverns and sub-soil pinnacles in the Pokhara Valley. Such sinkholes and pinnacles are frequently observed in Ghachok Formation. Soil erosion and landslides are other natural hazards that frequently occur in steep terrain. As a result of heavy rainfall in monsoon, a number of new landslides occur and many old and dormant landslides become active. These landslides are the sources of huge amount of loose sediments that cause loss of lives, damages of public properties, infrastructures, and siltation in Phewa and Begnas lakes. Haphazard mining of river gravel and sand has also created the problem of riverbank erosion and flooding in the rainy season. Several earthquake events greater than 4 Richter scale have occurred in the past within the Pokhara Valley and its close proximity. Of these the largest earthquake events were 7 Richter scale in 1939 and 6.5 Richter scale in 1954 by which the Pokhara Valley suffered considerable damages.

Unplanned urbanization, haphazard development of infrastructures and settlements, improper locations of industries, improper landuse, uncontrolled surface drain, haphazard disposal of municipal waste etc. are the root causes of environmental degradation in Pokhara Sub-Metropolitan.

All types of hazard prone areas are identified and categorized as low, medium and high hazard areas in Engineering and Environmental Geological map of the Pokhara Valley. The proposed recommendations are expected to be useful to the users in protecting environment and mitigating disasters.

INTRODUCTION

The Pokhara Valley is situated on the southern foothills of Annapurna and Machhapuchhre Himal in Western Nepal (Fig. 1). Pokhara is the regional headquarter of Western Nepal. It is famous because of its unique geology, spectacular Seti River gorges (narrow, deep gorges up to 56 m), karst features (sinkholes, caves, pinnacles, block falls), highest precipitation in the country (up to 4000 mm/year) and very fast infiltration (no water logging). Pokhara is also a famous tourist place of unique natural beauty. Rapid urbanization, unplanned infrastructure development activities, improper waste disposal, poor sewerage system, deforestation and stone quarries on the hill slope and haphazard gravel/sand mining on the river bed etc. are the root causes of environmental degradation in Pokhara.

The Pokhara Valley map area covers about 850 sq. km. Valley floor area is only about 250 sq. km. It is filled with ill-sorted, mixed, thick glacio-fluvial sediments derived from far north during catastrophic debris flow events in the past (Quaternary age). These sediments are rich in calcareous constituents. The highest point is the headwaters of Sardu Khola (4,885 m) and the lowest point is the Seti River bed at Gagangaunda (580 m).

A number of geologists, geomorphologists and geographers studied the Pokhara Valley for different purposes. Some of the works are very important regarding the origin of the Pokhara Valley and thick accumulation of valley fill sediments. Gurung (1965 and 1987) believed that

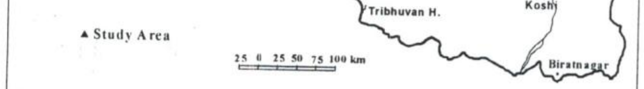

Fig. 1: Location map of the study area.

the Pokhara Valley is a tectonically controlled valley. Numerous lakes in the valley were formed due to the damming of the tributaries of the Seti River during catastrophic debris flow events, which are responsible for the deposition of Pokhara gravel. He suggested that rise of the Mahabharat Lekh in the south and subsidence of valley has helped to accumulate thick Quaternary sediment in the valley.

On the other hand, Hagen (1969) is of the opinion that Pokhara is a tectonic valley and there existed a big Pokhara lake, which was later filled up by catastrophic debris flow events in the past. Present lakes are the remnants and pushed aside lake of the bigger Pokhara lake.

Whereas Harmann (1974) believed that the formation of the Pokhara Valley was due to a tectonic subsidence of the basin itself. He divided the valley fill sediments into three groups and attributed them to three glacial ages. He believed that tectonic subsidence in the basin and glacial advance in the Great Himalayas was the cause of the thick gravel deposits in Pokhara Valley.

Akiba (1980) of the opinion of the existence of bigger Pokhara lake and deposition of thick sediments took place in this lake. Yamanka et al (1982) explored the Quarternary geology of Pokhara Valley and divided the sedimentary deposit into seven formations. Fort (1987) tried to relate the structural and climatic factors to the topography and bioclimatic gradients and concluded that rapid and catastrophic episode of Pokhara gravel aggradation could also serve as a model of geomorphological evolution of the Higher Himalayan Front in the central Himalaya.

Shrestha (1981) did the regional geological mapping and confirmed that the basement of Pokhara valley is composed of gritty phyllite and quartzite of Kunchha Formation. Shrestha et al. (1992) investigated some parts of the Pokhara valley fill sediments and suggested some of the techniques to detect hidden joints and caverns. In the following year Shakya (1991) did reconnaissance engineering geological mapping of some parts of Pokhara Valley Jnawali and Tuladhar (1996) compiled and published a geological map of some parts of Tanahu – Kaski - Syangja districts including part of Pokhara Valley.

Koirala and Rimal (1995) and DMG/ EGP project prepared an Engineering and Environment Geological Map of Pokhara Valley and Kaphle (1998) compiled all the available information/ data and prepared an explanatory report. Kaphle (1998) also did the environmental geological assessment of new settlement areas and infrastructure development plan in Pokhara Valley.

The main objective of the present research work was to identify various types of geo-environmental problems in Pokhara Valley and make their assessment and integrate available geo-scientific information in Urban Infrastructure Development Planning for Sustainable Development.

The methodology applied during research was literature review, data collection, data analysis, landsat image and aerial photo interpretation, field investigation, ground survey including outcrop information and laboratory analysis. GIS with Arc-Info was applied to store data, processing, display and production of Engineering and Environmental Geological Map (Fig. 2).

GENERAL GEOLOGY

Bedrock geology

The Pokhara Valley is an intramontane basin located in the middle mountain physiographic region of western Nepal. Bedrocks are exposed on the hill slopes around the basin and on the small hillocks in the valley. Bedrocks are represented by the metasedimentary rocks (quartzite, phyllite, slate), as well as metamorphic rocks (schist and gneiss) with or without thin layers of soil cover. The bed rocks are classified into four geological formations/ units namely Benighat Slates (bg) of Upper Nawakot Group and Fagfog Quartzite (fg) and Kunchha Formation (kn) of Lower Nawakot Group and Himalayan Gneiss (hmgn) of Higher Himalayan Crystalline Group (Fig. 2). Gritty phyllite and quartzite of Kunchha Formation of Pre-Cambrian age represent the basement of Pokhara valley.

Quaternary geology

Pokhara Valley is filled with thick accumulation of debris materials (ill-sorted mixed coarse calcareous gravel/ sediments) derived from far north in the Himalayan Region during 3 large catastrophic debris flow events, most probably related to three Glacial Age (Quaternary Age). The valley floor sediments are divided into 11 units. Out of these, alluvial terrace deposit (sal), colluvial soil (sco), residual soil (srs), alluvial fan (af) and lake sediment deposit (unlc) are Unconsolidated Sediments and Pokhara Formation (pk), Ghachok Formation (gh), Tallakot Formation (tk), Siswa Formation (sw), Begnas Formation (bn) and Undifferentiated Debris flow deposits (undf) are Consolidated Sediments. All these units are shown in Engineering and Environmental Geological Map (Fig. 2). Three distinct terraces of Tallakot Formation (>15,000 years B.P.), Ghachok Formation (11,000 - 15,000 years B.P.) and Pokhara Formation (700–1100 years B.P.) are clearly traceable on the left side of Seti River in the northern part of Pokhara. Karstification and sinkholes are developed in these three formations. Therefore, their composition, nature and engineering characteristics are briefly described.

Tallakot Formation is represented by highly calcareous cemented silt to boulder size conglomerate with main constituent of angular to sub angular fragments of limestone and few quartzite. Its thickness is up to 200m and the weathered loose yellow soil is up to 10m thick. This unit is prone to sinkhole development. Infiltration of surface water is high. It has moderate to high groundwater potential with deep groundwater level. This unit is suitable for ground water recharge. Bearing capacity is highly variable.

Fig. 2: Engineering and environmental geological map of Pokhara Valley.
(Legend contd. in next page)

(Contd. legend of Fig. 2)

EXPLANATORY LEGEND

ROCK/ SOIL TYPES AND THEIR ENGINEERING PROPERTIES based on their lithological homogeneity

GEOLOGICAL UNIT

Quaternary

Unconsolidated material

srs — **Residual soil**: Loamy to sandy gravel on hill slopes of Phewa lake catchment. Thickness variable, generally 1 m to 5 m, at some places more.

sco — **Colluvial soil**: Inhomogeneous deposit at foot slopes of Phewa lake catchment with composition of silt and sand, at places with boulders and humic on top. Thickness variable, generally more than 1 m increasing to the center.

af / nf — **Active (af) & nonactive (nf) alluvial fan deposit**: Poorly sorted gravel, sandy gravel, sand and silt; fine grained material toward the margin. Thickness generally increasing towards the center of fans.

sal — **Flood plain and Lower alluvial terrace deposit**: Gravel, sand, silt, and clay deposits.

unlc — **Undifferentiated lake deposit**: Soft to stiff calcareous silty clay to clayey silt interfingering with dark carbonaceous clay and clayey silt towards foot hills; pockets of peat occasionally present with thickness of 1 m to 6 m.

Consolidated sediment

pk — **Pokhara Formation**: **Debris flow deposit:** Slightly to moderately cemented silty and sandy gravel with main constituent of limestone, schist, gneiss and granite. Thickness highly variable but up to 80 m; at places up to 2 m soil cover present; some karst phenomena noticed near surface.

gh — **Ghachok Formation**: **Debris flow deposit:** grey to pale greenish grey with main constituents of limestone fragments of boulder to silt size and occur below the formation. Thickness up to 100 m. In the central part highly calcareous cemented conglomerate. At places, weathering to loose pale green silty soil as a 1-3 m thick top layer.

tk — **Tallakot Formation**: **Debris flow deposit:** Highly calcareous, cemented silt to boulder sized conglomerate with main constituent of limestone fragment; thickness up to 200 m; weathering to loose yellow soil up to 10 m in thickness.

sw — **Siswa Formation**: Grey, moderately to weakly compact silty to sandy gravel derived from surrounding hillside. Deeply weathered near surface; thickness up to 20 m.

bn — **Begnas Formation**: **Debris flow deposit:** Light grey to yellowish grey, highly calcareous, cemented and very hard conglomerate with main constituent being limestone, gneiss, quartzite and schist; thickness up to 50 m.

Hardrock

undf — **Undifferentiated debris flow deposit**: **Debris flow deposit:** Grey to yellowish grey, stiff gravelly silty sand to silty sandy gravel with clasts of gneiss, quartzite, schist and amphibolite. Slightly calcareous at places. Weathered product is yellowish grey soil with concretions at places; thickness up to 50 m.

Precambrian to Paleozoic

bg — **Benighat Slate**: Dark blue-grey slate and phyllite, occasionally carbonaceous. North of Tallakot near MCT the formation is dominantly graphitic schist with some garnetiferous chlorite schist and carbonates.

fg / phy — **Fagfog Quartzite**: Fine-grained, massive, quartzite but bedded in upper part. Intercalation of green phyllite (phy) and basic rocks at places; thickness up to 1000 m.

kn / qz / ulgn — **Kuncha Formation**: Gritty phyllite and quartzite (qz) interbedded in different ratios; thickness several thousand meters. Ullery Gneiss (ulgn) consists of Augen-gneiss with interbedded schist.

NATURAL HAZARDS AND FOUNDATION INSTABILITIES

Areas of sinkhole or subsidence hazard or of low load bearing capacity

- High hazard of sinkhole development and subsidence, and widespread movement of polluted water along underground solution channels.
- Medium hazard of sinkhole development and subsidence
- Low hazard of sinkhole development and subsidence.
- Area susceptible to subsidence due to soft clay, peat, and lime muc

Mass movement and erosion

- Old landslide
- Active landslide

For landslide risk minimisation, proper internal and external slope drainage, removal of unstable material, reduction of slope angle, and restraining structures recommended. No construction should be allowed near active landslide areas.

Rock fall, block fall and river bank collapse:
Teeth show direction of movement.

- Area susceptible to **very high hazard** due to block fall and river bank collapse. Acute damages apparent. ***Recommendation:*** *No buildings should be allowed within 75 m distance from the cliff. No excavation and other activities to cause bank undercutting should not be allowed.*
- Area susceptible to **medium to high hazard** due to block fall and river bank collapse. No recent damage reported. ***Recommendation:*** *Construction of new buildings within 75 m of cliff should be discouraged otherwise need detailed site investigations. No excavation and undercutting should be allowed along the riverbanks.*

Gully erosion

Construction of check dams to control floods, and reduce torrential activity and erosion of soil. ***Recommendation:*** *Retaining walls with deep seated foundation recommended wherever construction activity required*

Flood prone areas

- Area of annual floods — Good land for irrigated and non-irriga cultivation. ***Recommendation:*** *Buildir should not be allowed. Storage chemicals and other hazardous mate as well as waste disposal strictly prohibit*
- Area of potential flood hazard — Suitable ground for agricultural a recreational purposes. ***Recommendati*** *Buildings should not be allowed otherw need special flood protection. No stora of hazardous material and waste dispo:*

OTHER FEATURES OF ENVIRONMENTAL SIGNIFICANCE

Areas with mineral resources

- Potential location for sand (S), gravel (G) and blockstone (B) quarries. Identification of additional construction material resources require further investigation. Quality and quantity for future development can be assured by detailed investigations.
- Existing excavation sites for exploitation of sand (S), gravel (G) and boulders (B) with local or regional economic importance

Waste disposal site

- Existing area of landfill without proper geological consideration. ***Recommendation:*** *Detailed investigation is recommended for technical improvement of the landfill.*

Industrial area

- Industrial area with probable environmental impact. ***Recommendation:*** *Regular monitoring of groundwater /surface water is recommended*

OTHER SYMBOLS

- Thrust (MCT=Main Central Thrust)
- Lineament, fault
- Anticline, syncline
- Location of Standard Penetration Test
- River, lake, spring
- Contour line in feet
- Built-up area
- Dip and strike in degrees
- Sinkhole
- Spot height in feet
- Dam

Ghachok Formation consists of ill-sorted angular to sub-angular gravel, cobbles, and boulder well cemented with light brown calcareous silty matrix. The gravels are mainly of limestone and few sandstone, shale, gneiss, quartzite and schist. At places cone shaped pinnacles are developed in the upper part of Ghachok Formation and depression between pinnacles are filled with some soils, gravels, cobbles and boulders. Karstification is widespread in the form of sinkholes, cavities and subsoil pinnacles. There is high risk of subsidence when it lies under thin cover of Pokhara Formation. The bearing capacity is highly variable. There is high potential for groundwater in karstified parts but groundwater level is deep and chances of water pollution are high. This unit is suitable for groundwater recharge.

Pokhara Formation is more or less similar to Ghachok Formation in its composition, roundness and sorting. The only difference is that the boulders and rock fragments (gravels) are comparatively smaller in size. This unit is prone to subsidence when its thickness is small (<3 m). There is a risk of bank collapse along escarpment. It is potential for groundwater in the karstified formation with deep groundwater level but pollution likely. Bearing capacity is highly variable.

DEPOSITIONAL HISTORY OF POKHARA SEDIMENTS

In the beginning Seti River was flowing over the basement rock of Kunchha Formation (Pre-Cambrian age). Some tectonic activities started in the north and heavy erosion, huge landslides, mountain collapse and Glacial Lake Outburst Flood (GLOF) occurred over there. As a result catastrophic debris flow started flowing downwards all along the Seti River. Such three catastrophic debris flow events in three different times in the past brought down the huge amount of coarse sediments and deposited in Pokhara Valley. These deposits are named as Tallakot Formation, Ghachok Formation and Pokhara Formation. At the same time slight rise of the Mahabharat range in the south by tectonic activities might have facilitated to accumulate the sediments in the 50 km long and about 5 km wide stretch of the Pokhara Valley. Debris flow all along the Seti River has transported the huge amount of material from the north and thick ill-sorted sediments were deposited. Recent study was able to divide these sedimentary deposits into 6 different formations based on their superposition, although there is little variation in the composition of the sediments. Only the differences are in compaction, weathering, content of the amount of crystalline component and the degree of roundness of the clasts.

GEOLOGICAL HAZARDS AND RELATED ENVIRONMENTAL PROBLEMS

Pokhara Sub-Metropolitan City is facing the problem of geological hazards and environmental degradation. The valley floor sediments susceptible to different risks and hazards are identified and differentiated on the basis of their composition, degree of compaction, degree of segmentation and types of cementing material and they are described according to the Unified Soil Classification System. The degree of risk hazard is directly related to topography, slope, geology, structure, climatic condition, engineering properties of the rock and soil.

Geological hazards

The valley fill sediments are represented by coarse ill-sorted gravel, which are rich in calcareous constituents. Karstification and sinkhole development is quite common in some areas occupied mainly by Ghachok Formation. Fast deepening of Seti River and pronounced scouring of riverbanks resulting bank toppling, block fall along the banks of Seti River and its tributaries, land subsidence due to sinkholes, underground cavities/ cavern and areas occupied by soft lacustrine deposits and low bearing capacity areas represented by water saturated soft lake sediments also create hazards and geo-environmental problems Kaphle et al. (2000). Similarly, low lands by the sides of Seti and other streams are prone to flood hazard (e.g. Laltin Bazar etc.). Loose materials of the flood plain and lower alluvial terrace deposits are susceptible to liquefaction/ earthquake hazard. Soil erosion and landslides on hill-slopes in the surrounding hills and siltation in lakes and rivers are other geological hazards in Pokhara Valley. Such geological hazards need proper attention for mitigation.

Low Bearing Capacity Areas

In the map low bearing capacity areas are represented by the water saturated soft lake sediments like clay, peat and lime mud that are susceptible to differential settlement. Such areas are marked by vertical hatchings (Fig. 2). Construction of buildings and other heavy structures in such areas can create subsidence problem. Strip or mat or pile foundations are recommended for specific type of building construction in this area.

Flood Prone Areas

Low lands by the side of Seti River, Marda Khola, Yangdi Khola, Harpan Khola and Bijayapur Khola are prone to flood hazard. These areas are commonly followed the present river network (Fig. 2). Flood prone areas are not suitable for settlements. However, such areas can be used for dry and wet cultivation, green belts, and open spaces for recreation parks etc. These areas have high potentials for ground water but highly vulnerable to pollution. Therefore, such areas should not be used for settlement, waste disposal site, chemicals and oil/ gas storage etc. Legal or illegal settlements by the sides of Seti River in Laltin Bazaar, Mahendrapool, east of Airport and Bus park on the right bank of Seti River and other places are contributing a lot to the environmental degradation in Pokhara.

Sinkholes, Land Subsidence Hazard

Phyllite and quartzite of Kuncha Formation represent the basement of Pokhara valley. Calcareous constituents (clasts and cementing materials) dominate the overlying valley fill sedimentary sequence and they are locally susceptible to sinkholes development and subsidence hazard. Formations susceptible to subsidence are the lacustrine deposits, Ghachok Formation, Tallakot Formation, Begnas Formation and Pokhara Formation (Fig. 2). Dissolution (solution weathering) of these calcareous constituents helped to produce underground cavities, caverns, solution channels and other karst features like sinkholes and pinnacles etc. Such cavities can be seen in Gupteshor cave, Davi's fall and elsewhere. The effect of karstification is visible more prominently as pinnacles, in many places where Ghachok Formation is dominant in Chhorepatan area, Ghachok, Hyangja Bensi etc. Intense karstification has been developed because of the existence of vertical cracks parallel to the Seti gorge. One of the major causes of the failure of Seti Highway bridge in Pokhara (in 1991) was because of karstification below foundation of the abutment of bridge itself. Ghachok Formation is susceptible to karst feature development in Pokhara. But in the area occupied or covered with Pokhara Formation with occasional hard pan overlying the highly karstified Ghachok Formatin does not show any sinkhole. In this case, 2-3 m thick Pokhara Formation acts as a roof over the karst features.

Sinkholes in Pokhara, the collapse features on the ground at the surface resulting from washing away of underground filling calcareous materials of a paleo-karst by various reasons e.g. underground channel erosion, solution cavities development etc. Recent investigation noted that the area of frequent sinkhole development in Pokhara Metropolitan are in the central part of Pokhara city (ward no. 3, 4, 7, and 8), Seti highway bridge area (ward 9), Mahendra cave area (ward 16), Gupteshor (ward 17) and Davi's fall area in Chhorepatan (Fig. 2). However, the intensity of sinkhole development is not the same even in the same formation. The causes that help to promote sinkholes are identified as the composition of the underground material. Dissolution of the calcareous constituents is a continuous phenomenon so far as the percolation of water from the ground continued.

In the map all the areas with medium to nigh risk (orange coloured area) and low risk (dark yellow coloured area) for land subsidence and sinkhole development are marked (Fig. 2). Construction of more than two storey buildings and other heavy structures in these areas must be discouraged. It is necessary to maintain proper surface drainage system. Detail site investigation specific to the structure is essential prior construction.

Landslide and Soil Erosion

Quite a few active and dormant landslides of various size are recorded on the hill side slope. Soil erosion is a common problem in the hilly region of Pokhara (Fig. 2). Improper land use, cultivation in steep slope, improper irrigation in agricultural field (sloping terraces), haphazard exploitation of construction materials, soft and fast weathering nature of rock/ soil and deforestation are the root causes of landslide and soil erosion in this area. Active and dormant landslides and areas susceptible to rock fall and gully erosion are delineated in the map and shown by standard symbols of red line works. Various protective measures like bioengineering works, construction of check dams, maintenance of internal and surface drainage, removal of unstable materials, reduction of slope angle are very much helpful to overcome these problems. Application of all these items in Phewa lake, Begnas lake and Rupa lake catchment areas are recommended to control landslide and soil erosion problems. The areas prone to block fall (mainly on the banks of Seti gorge) are outlined with recommendation for the mitigation measures. Collapse of Prithivi Highway Bridge over Seti River in 1991 is due to bank scouring and sinkhole development that caused block fall. Development of a 70 cm wide crack in April 1998 to 4.2 m wide in April 2000 of over 150 m long on the left bank (upstream as well as downstream) of the newly constructed Highway Bridge site and collapse of some part of it (by September 2001). Fig. 3 clearly indicates that the process of bank cutting and hydraulic action particularly during monsoon causing block falls and continuesly are in operation. Such processes are adversely affecting the foundation of the newly constructed highway bridge and may cause early damage (before expected time).

Fig. 3: Riverbank cutting and block fall by the side of Seti River at highway bridge site.

Table 1: Active Faults Located Nearest to the Pokhara Valley.

No.	Fault Name	Fault Index	Assigned Max. Magnitude (Ms)	Approximate aerial Distance from Pokhara (km)
1	Thak Khola Graben	HTH 5.7.1	7.2	40
2	Darma-Dhaulagiri	MCT 3.2.4	7.1	80
3	Dhorpatan-Barigad	LH 4.5.1	7.2	50
4	Arung Khola	MBT 2.3	7.5	40
5	Baraghat	HFF 1.8	6.7	60

Earthquake and Liquefaction Hazards

The Earthquake Catalogue of Nepal shows that several earthquake events greater than 4 Richter scale occurred in the Pokhara Valley and its close proximity (Table 1). Of these, the largest event was of a 7 Richter earthquake of 1936, and the second largest event was of a 6.5 in 1954. Three earthquakes with magnitude between 5 and 6 Richter scale have been recorded. In addition to that nine events with magnitude between 4 and 5 Richter scale were also recorded. Pokhara suffered damages due to the large events, but the information about damage is scanty. There are several active faults in the surrounding regions but within the Pokhara Valley, no active fault is detected. Nevertheless the Pokhara Valley is prone to earthquake hazard due to regional geo-structural framework. Therefore, it is imperative that any building construction in the valley should strictly follow the National Building Code (BCDP 1994).

Earthquakes generally trigger liquefaction in unconsolidated saturated sediments. In the Engineering and Environmental Geological Map of Pokhara Valley (Koirala et al 1997) the surfaciel deposits like loose materials of the flood plain and lower alluvial terraces are classified as highly susceptible to liquefaction, while the residual, colluvial soils and the deposits of the active and non-active alluvial fan have been classified as materials with low liquefaction susceptibility. Such classification has been made for the purpose of guidance only. For larger structures, detail site specific analysis of liquefaction possibility should be carried out for the design of the foundation of the structures, if they are proposed within these soil types.

Industrial and Construction Material Mining Hazards

There are quite a few small and medium scale industries in Pokhra. Most of them are located within the industrial estate, near residential area of Amarsingh Chawok. Few other small industries like soap factories, concrete block/ pole factories etc. are located by the side of Seti River. Improper location of some of these industries and uncontrolled discharge of industrial waste into the rivers, and open spaces and smoke from the chimney of some of the industries are the causes of environmental degradation. In addition to that haphazard exploitation of construction materials such as sand, silt, boulder from the riverbeds have helped in river scouring and block falls (Fig. 4). Block stone and roofing slate quarries in sloping terrain have also created the problem of deforestation, which causes soil erosion and landslide on the hill slopes and siltation in the lakes and streams/ rivers.

Siltation and Eutrophism

Soil erosion and landslides in the hill slopes have contributed huge mass of sediment causing siltation problem in Phewa, Begnas and Rupa lakes. As a result the size of Phewa lake has reduced considerably (Fig. 5). The problem of eutrophism in these lakes is mainly caused due to fecal contamination and chemical fertilizer used in the cultivated fields in the catchment areas. As a result, the lake water is highly polluted and very rich in colliform bacteria.

ENVIRONMENTAL DEGRADATION AND POLLUTION

Fast population growth, unplanned housing and infrastructure development, haphazard urban sprawl without considering geological condition and natural hazards (flood and landslide prone areas, river banks etc.), haphazard disposal of municipal, hospital and industrial wastes in Seti River, connection of sewerage pipes to Firke Khola, Seti River and Phewa Lake causing surface and GW pollution. Soil erosion and landslides on the hill slopes contribute huge amount of sediments annually causing siltation in Phewa and other lakes.

The natural ecosystem in the lakes and rivers is deteriorating due to eutrophism by fecal contamination, use of chemical fertilizer and insecticide in the agricultural fields in the catchment areas, human encroachment of environmentally sensitive marginal lands (e.g. Phewa Lake

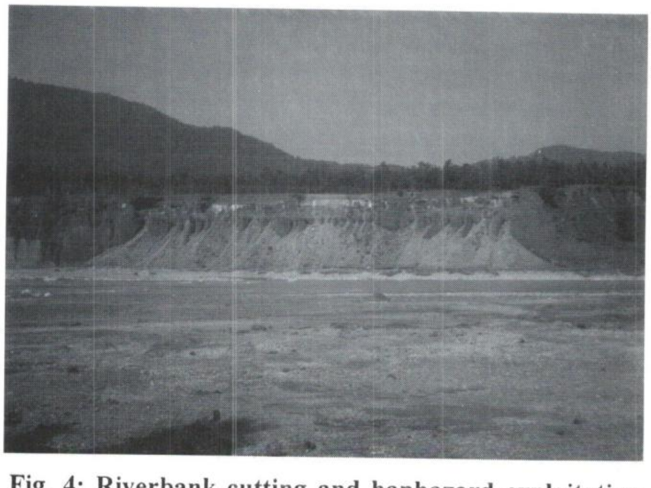

Fig. 4: Riverbank cutting and haphazard exploitation of gravel from Seti River Bed.

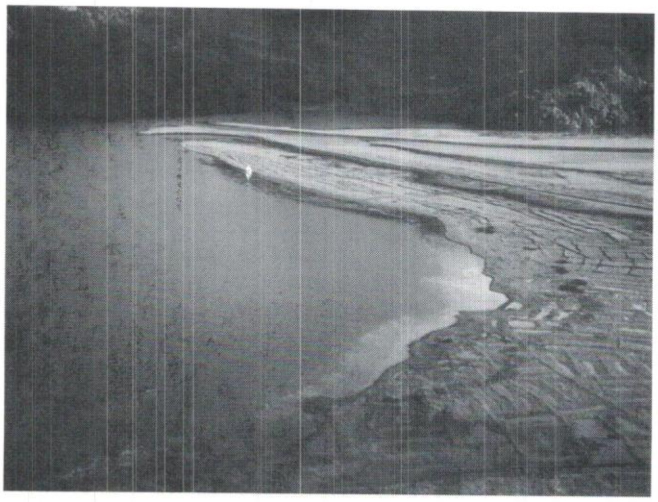

Fig. 5: Siltation in Phewa Lake and its size reduction.

site, close to bus park, east of the airport, bridge sites, roadsides, Seti River banks etc.).

Uncontrolled mining of sand, gravel, boulder in river beds increases vulnerability to river bank cutting, blockfall and flooding and quarry operation on the hill slopes created slope instabilities resulting soil erosion and landslides.

Fumes from the factories, vehicles and recent practice of burning plastics, tires are common causes of air pollution.

CONCLUSION

Engineering and Environment geological map is intended as a support for sustainable land use planning, regional and urban planning, natural resources management planning, infrastructure development (roads, bridges, sewerage treatment plant etc.) planning, selection of potential sites for waste disposal, location of potential sites for extraction of construction materials, hazard mitigation planning, conservation of natural resources for environmental protection and sustainable utilization, identification of ground and surface water sources, ground water level, water quality and disaster mitigation. However, it should not be used as the only basis for any specific site investigation of individual building and structure. It cannot replace the detail site investigation process.

Karstification, sinkhole development and land subsidence cause frequent foundation problem in Pokhara town since most parts of the settlements lie on Ghachok Formation which is of public concern.

The ground occupied by Ghachok Formation and Pokhara Formation as well as areas occupied by soft lacustrine sediments having low bearing capacity are under high risk of subsidence. Similarly marginal low lands by the side of Seti River are prone to flood and cliff faces are prone to block falls. Siltation, eutrophism and water pollution in lakes are the other environmental problems in Pokhara.

Karstified rocks of Ghachok and Pokhara formations have potentiality for ground water in general. Nevertheless, ground water level in Pokhara is very deep (>50 m). The area underlain by these formations are also potential ground water zones. These formations are also suitable for ground water recharge but prone to pollution due to high infiltration rate if sewage and other urban waste is not properly managed.

RECOMMENDATION

It is suggested to integrate all available geo-scientific information in the regional and urban development activities, hazard mitigation and environment protection of Pokhara Valley to minimize the risk of hazard and protect natural environment from further deterioration.

The municipality should discourage the people to construct heavy structures in the areas occupied by lacustrine sediments, karstified sinkhole prone areas, in the vicinity of Devis' fall, Gupteshor cave in areas occupied by Ghachok Formation, within 70 m on either side of Seti River banks, flood prone low lands, etc. Shallow foundation posses risk of differential settlement. Therefore, pad footing up to 2 m depth or strip or raft foundation is recommended.

It is recommended that Pokhara Valley Town Development Committee, Pokhara Sub-Metropolitan City, Department of Housing/ Regional Directorate and Lekhnath Municipality should work in close cooperation and follow National EIA Guidelines and also enforce National Building Code and other rules and regulations imposed by the government in urban and infrastructure development plans.

Direct connections of sewerage pipes, industrial effluents, hospital waste water to the rivers/ lakes without prior treatment must be stopped. It is advised to dispose municipal waste and other solid wastes in a geo-technically suitable landfill site away from the settlements, airport, hospital, drinking water sources, etc.

Exploitation of natural resources must be carried out under strict supervision of concerned technical staff with minimum environmental damage.

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