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Assessment of barrier potential of sediments for selection of waste disposal sites in the Kathmandu Valley

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ABSTRACT

The Kathmandu Valley is an intramontane basin filled with fluvio-lacustrine sediments of Quaternary age. The deposits of the valley comprise lake sediments that accumulated due to damming of the Bagmati River system during Plio-Pleistocene time as a consequence of rise of the Mahabharat Range. The northern and north-eastern parts of the basin are occupied by coarse sediments mainly micaceous sand and gravel derived from the Sheopuri gneiss, while in the central and southern part of the valley, these occur very fine sediments mostly black carbonaceous clay with lignite and diatomaceous earth at places. The maximum thickness of the sediments as revealed by the deepest drill hole in the valley is about 550 m at the central part. The valley floor has a highly undulating topography with buried ridges of Precambrian basement rocks.

The Kathmandu Valley with population of around 1.5 million is witnessing rapid urban growth, unplanned development and environmental degradation leading to increased pollution. Consequently, the valley is confronted with major problem of safe disposal of urban waste produced at a scale of 500 tones per day. This is largely due to lack of awareness and realization at planning and decision-making levels about the importance of geo-scientific information in identification of suitable landfill sites for solid waste management. This paper attempts to deal with the waste disposal problem by preparing a geo-scientific map showing the potential areas for selecting proper landfill sites based on assessment of subsurface sediments in combination with other relevant aspects related to waste disposal.

The assessment of barrier potential of sediments is based on the lithological description of bore holes to a depth of 7 m assuming that clay has a high barrier potential, silty to fine sandy sediments have moderate and sandy to gravelly sediments have low barrier potential. The thickness of low-permeable zone has to be at least 5 m to act as natural barrier against toxic leachate originating from waste to protect the groundwater. The effectiveness of such a barrier against migrating pollutants depends on the ability of this layer to retard or exchange pollutants and fix them into soil complex. This is evaluated by determining the Cation Exchange Capacity (CEC) values of the soil derived from laboratory analysis of samples taken down to 2 m depth. Other important parameters for an estimation of the soil barrier function are percolation rate, soil texture, grain-size and soil depth.

Using GIS ARC/INFO, a map has been prepared delineating areas of barrier potential in three classes: high, moderate and low. The high barrier potential areas are considered as the most favourable sites for waste disposal, whereas the low barrier potential zones are assessed as the negative areas that should not be considered for selecting waste disposal sites. These three groups in conjunction with other selecting criteria (e.g., infrastructures, settlements, water bodies, cultural heritage sites etc.) are presented on a map at a scale of 1:50000. This map provides a good basis for planners and decision-makers for selecting geo-scientifically viable landfill sites for urban waste management.

Based on this map, six sites were selected for further investigation by drilling up to 8 m depth. Taikabu of Chetdol (Bhaktapur) turned out to be the most promising site for development of a sanitary landfill for long-term management of urban waste of the Kathmandu Valley.

GENERAL INTRODUCTION AND BACKGROUND

The Kathmandu Valley with its steadily increasing population of about 1.5 million at present is confronting serious environmental problems through its increasing volume of waste generated at a scale of about 500 tons per day. Particularly after the closure of Gokarna landfill (Fig. 1), waste disposal problem has become more serious obviously due to lack of suitable site for immediate use. The Kathmandu Metropolitan City is currently dumping its waste along the Bagmati River directly at the river-bed near Balkhu (Fig. 2) as a temporary means of crisis management, despite knowing the fact that it is polluting the river as well as groundwater. With the changing way of living style, the simple harmless urban waste has also changed to a more complex and hazardous substances posing more and more threats to the living conditions of the people. Waste disposal is a problem that increasingly demands the attention of scientists, engineers, policy-makers and the general public. Therefore, the selection and development of a suitable sanitary landfill is a multi-disciplinary task and requires a series of activities. One of the first steps is the identification of areas with sufficient geological barrier potential to avoid pollution of subsoil and groundwater by toxic leachate originating from disposal of waste. For any scientific planning

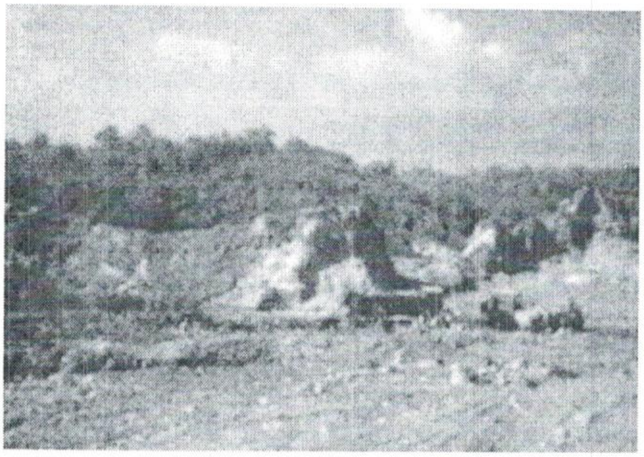

Fig. 1: Abandoned landfill site at Gokarna.

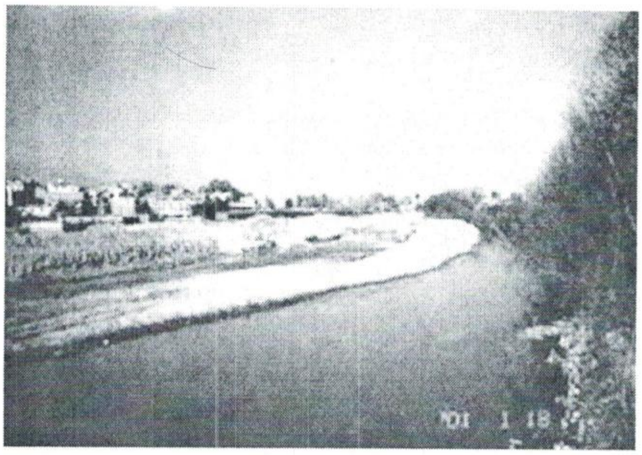

Fig. 2: Municipal waste presently dumping along the Bagmati River near Balkhu.

and management of urban waste, the planners and decision-makers need appropriate information about landuse and soil/rock condition on suitable map scale. Areas containing low-permeability sediments with thickness of at least 5 m and high cation exchange capacity (CEC) as potential areas for waste disposal must be clearly shown on the map in contrast to non-favourable areas of high-permeability sediments with a low cation exchange capacity. In case of non-availability of ideal site (low-permeable ground with high CEC values), areas underlain by medium-permeability sediments can also be considered for landfill development only with special technical measures.

Keeping in view of these important geo-scientific inputs required for long-term planning of urban waste management in the Kathmandu Valley, the Department of Mines and Geology (DMG) with technical assistance of the Federal Institute for Geo-sciences and Natural Resources (BGR)/ Germany has produced a Barrier Potential Map of the sediments of the Kathmandu Valley after investigation of subsurface geology, soil, hydrogeology and other relevant aspects. This paper is essentially based on the findings of this study undertaken by DMG team led by H. Aust, a short term expert from BGR (Aust et al. 1999).

GEOMORPHOLOGY AND GEOLOGY OF THE VALLEY

The Kathmandu Valley is an intramontane basin surrounded by the Mahabharat range to the south and Sheopuri hills to the north. It was a lake during the Plio-Pleistocene times when the palaeo-Bagmati River was dammed by rapid upheaval of the Mahabharat range. The lake was gradually filled up by lacustrine and deltaic river sediments (Dongol 1985) eventually draining the water through a gorge at Chobhar. The northern and eastern parts of the basin are occupied by coarse micaceous sand and gravel sediments derived from the Sheopuri gneiss, while in the central and southern part of the valley, these occur very fine sediments mostly black carbonaceous clay with lignite and diatomaceous earth at places. The maximum thickness of the sediments as revealed by the deepest drill-hole in the valley is about 550 m at the central part at Bhrikutimandap (Gas Project Report 1988). Bore-hole data acquired so far of the Kathmandu Valley indicate that 33 drill-holes have reached the basement rock while the others are still in soft sedimentary deposits. This implies that the valley floor has a highly undulating topography with burried ridges of mostly Pre-Cambrian rocks.

The basement rocks are composed of gneiss, schists, phyllites and limestones of Kathmandu Complex (Stocklin and Bhattarai 1978). The northern mountain range consists almost exclusively of gneiss and granites while the southern range is underlain by limestone, marble, phyllite and quartzite of Paleozoic age.

METHODOLOGY OF ASSESSMENT

Subsurface soil

The delineation of barrier potential zones is based on the evaluation of soil to a depth of 2 m and litho-sediments up to a depth of 7 m obtained by augering. The protective effect of unconsolidated material above an aquifer is of decisive importance for assessing the barrier of these layers. The effectiveness of a protective layer against pollutants from waste disposal, fertilizers, pesticides and abandoned hazardous sites needs the knowledge of factor which prevent the migration of pollutants through this layer "geologic barrier". The ability of this layer to retard or exchange pollutants and fixing them into soil complex is defined as the barrier potential. This is grouped into various classes according to the measured cation exchange values ranking from high to low.

Cation Exchange Capacity (CEC) is the capability of soils to absorb solved substances at their surface. The potential cation exchange capacity is determined by the type and content of clay minerals and organic matter of the soil. CEC values were determined in the laboratory by analysing

Ca, Mg, K, Na in the soil samples taking into account of two important parameters, percolation rate and soil texture/ grain size (permeability).

Lithological Logs

Assessment is based on the lithological description of existing bore-holes. Ideally a 5 m thick barrier with permeability k_f value less than 10^{-7} m/s is required under a landfill site for solid waste disposal. It is assumed that the protective effectiveness of such a geologic barrier is high enough to minimize the risk of groundwater contamination by migrating leachate from the waste. In the present case, assessment of the sediments has been made for 7 m thickness as the bore-hole data are available for 0-7 m. In the Kathmandu Valley, the surrounding metamorphic rocks are not recommended for the selection of landfill site due to tectonic stress and occurrence of faults, fractures and fissures. Therefore, present assessment was confined to the valley floor area.

The suitable barrier sediments are clay and silty-clay with sufficient retarding or retaining capacity for percolating liquids. Clay and silt are sediments with a low permeability favourable for retaining leachate with a high adsorption capacity for cations. During very slow passage of contaminated water through the clay barrier, most of the contaminants are supposed to be filtered out.

In the context of lithological description and grain size, international standards were used as the grain size parameter is of utmost importance in assessing the barrier function. Lithological information from bore-hole logs were transferred into computer using MS-Excel and then processed using Surfer software to create maps showing the distribution of lithological units with barrier potential classes as high, moderate and low.

PROCEDURE OF DELINEATING BARRIER UNITS AND MAP PREPARATION

GIS with Arc/Info was used for data storage, processing and map preparation. Cartographic work was completed with Freehand programme. A special procedure was devised to delineate barrier units of varying permeability potential and cation exchange capacity.

Step one: All areas with low-permeability ground that are assessed as positive areas owing to their natural properties were defined.

Step two: All areas covered by settlements that are sensitive to landfill proximity (assessed as negative areas) were determined.

Step three: Area prone to natural hazards such as flood plains, seismic liquefaction zones etc. (assessed as negative) was delineated.

Final step: Map areas identified in steps two and three were superimposed on the areas with a high barrier potential determined in step one. Areas in which a high barrier potential coincides with the negative areas of steps two and three were eliminated from further consideration.

Two types of maps formed the basis of this evaluation. The first map was based on the grain size evaluation of lithological bore-hole logs of the top 7 m prepared by Munestermann (Kharel et al. 1998).

The sediments were grouped into following three classes:

High barrier potential: Over 5 m clay, silty-clay or clayey silt (very low to low permeability).

Moderate barrier potential: Over 5 m clay to silt, silty sand, sandy silt or fine sand.

Low barrier potential: Less than 5 m clay to fine sand and mainly medium to coarse sand with some gravel (high permeability).

The second map was based on CEC values of soils (in mmol/100 g) derived from chemical analysis of samples taken down to 2 m depth (Kharel et al. 1998). The derivative of these two maps is the final Barrier Potential Map (Fig. 3) with the remaining positive barrier units that are of interest for selection of favourable waste disposal sites. This map essentially indicates three classes of barrier potential:

High barrier potential: Clay, silt, loam (CEC >16 mmol/ 100 g)- Favourable to waste disposal.

Moderate barrier potential: Loam, silt (CEC 12-16 mmol/ 100 g)- Possible only with special technical measures.

Low barrier potential: Sand, gravel, silt (CEC <12 mmol/ 100 g) – Unfavourable.

DISTRIBUTION OF BARRIER POTENTIAL ZONES IN THE VALLEY

The areas of high barrier-potential extend in the south, southeast and west within the valley particularly in Sunakothi, Panga and Thimi-Bhaktapur areas. These areas correspond with the Kalimati Formation (Shrestha et al. 1998, Kaphle and Joshi 1998) and Chapagaon Formation. The areas southwest of Harisiddhi, east of Bhaktapur and around have a particularly good soil condition for waste disposal.

The areas of moderate barrier- potential are found in the southern part of the valley west of the Nakkhu Khola and in the eastern margin of Bhaktapur. Minor patches also occur in the northern part of the valley. These areas are associated with different formations (e.g., Kalimati, Lukundol and Gokarna formations). The areas underlain by these formations can only be considered for waste disposal if mineral or plastic liners are used.

Sediments and soils with a low barrier potential cover extensive areas dominantly in the northern part of the valley

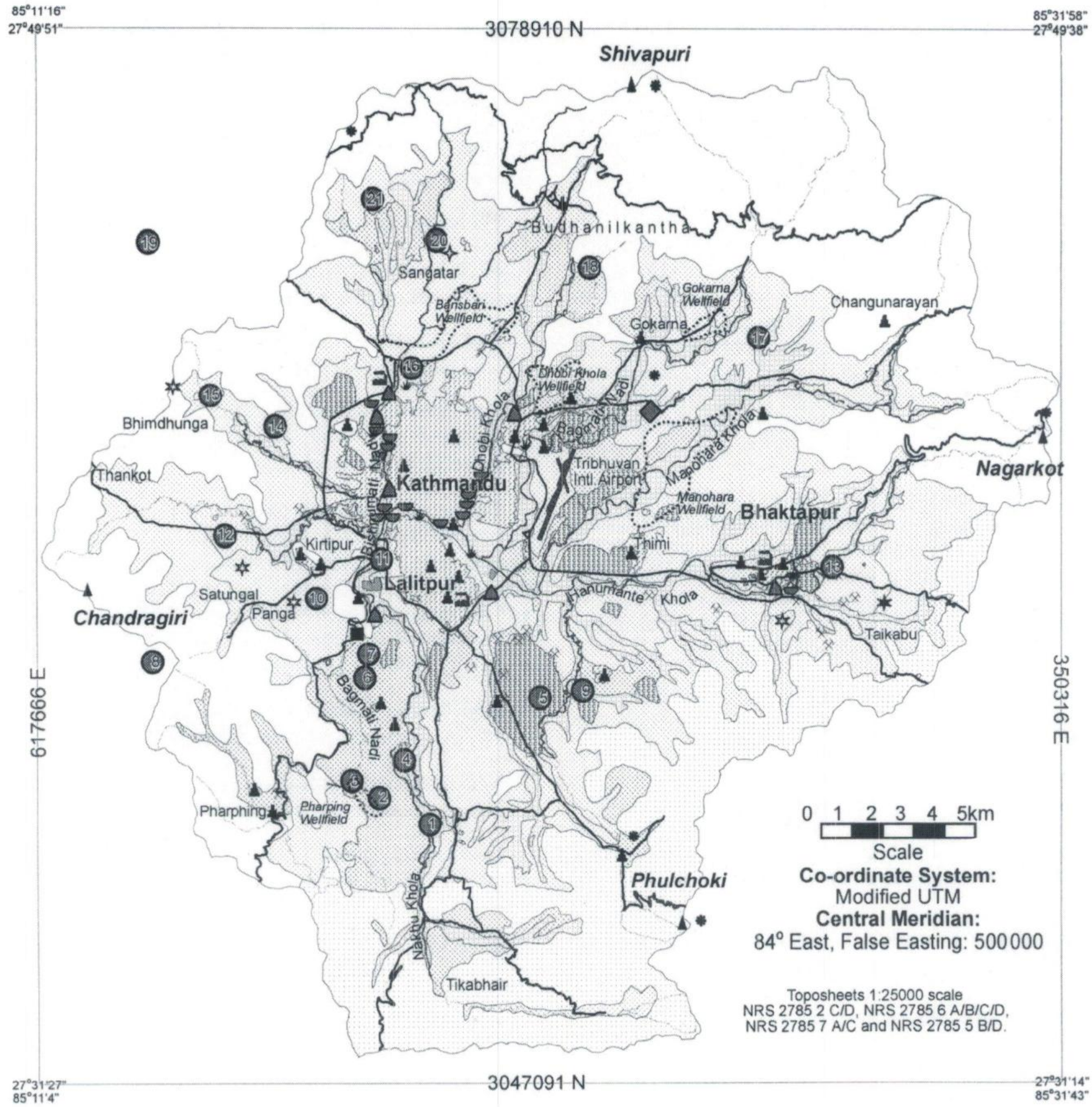

Fig. 3: Potential areas for waste disposal in the Kathmandu Valley.
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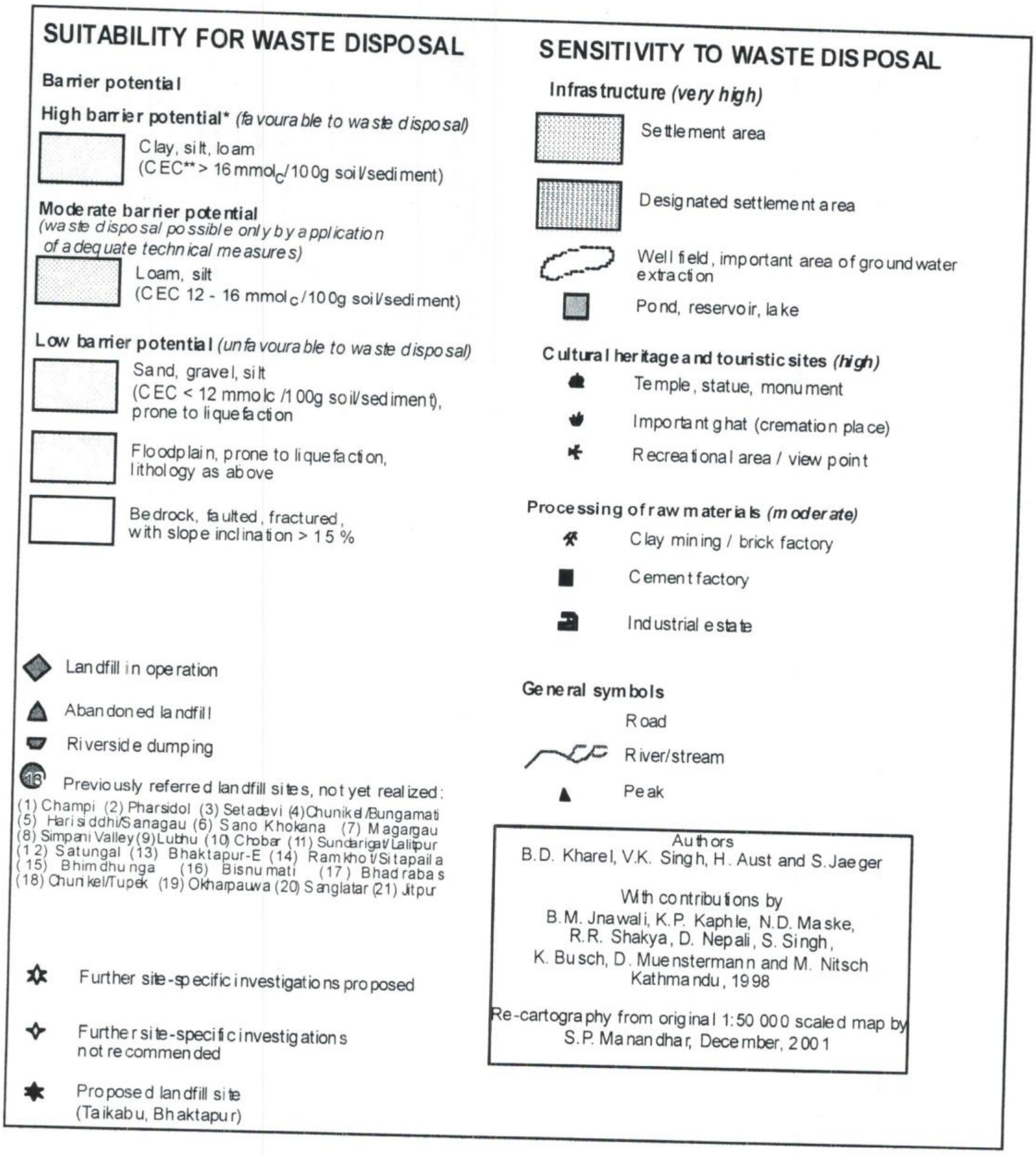
Legend of Fig. 3 (contd.)



with minor patches in the west and southern margins of the valley. These zones predominantly overlie the Gokarna and Tokha formations consisting mainly of sand and gravel sediments. The areas underlain by these low barrier potential sediments act as very good recharge zones for groundwater in the Kathmandu Valley. This category also includes flood-plains where any kind of waste disposal activity should not be allowed due to high risk of water contamination. Moreover, terrain of this type is usually prone to seismic liquefaction.

The areas underlain by hard rocks in the surrounding hills have been considered as having a low barrier potential because these rocks often contain fissures and fractures making them highly permeable. Groundwater will be easily affected by the leachate from the waste. Furthermore, the bedrock-exposed terrain generally has slopes more than 15 which does not provide adequate slope stability for a landfill.

OTHER SENSITIVE POINTS TO WASTE DISPOSAL

Settlement area

The areas covered by settlements are excluded for selection of waste disposal sites. In cooperation with urban planners, protection zones have to be worked out defining the minimum distance between settlement area and a landfill.

Water well-field or site of groundwater abstraction

Groundwater is an important resource for people and livestock. Therefore it is essential to protect well-fields against any kind of pollution arising from waste disposal.

Spring, pond, reservoir and lake

Waste disposal should not affect these elements by seepage of leachate. Landfill site should be located sufficiently away from these resources.

Airport

Aviation is very sensitive to several kinds of impact for safety reason. One of the possible interference to the aircraft is that of bird strike resulting from a landfill's attraction to birds and other animals. The safety radius around an airport recommended by ICAO is 13 km. Within an area of this radius, there should not exist any landfill. However, Hahn et al (1999) on behalf of GTZ have recommended for Nepal 5-10 km distance with certain conditions, over 10km without any special conditions.

Cultural heritage and tourist sites

This aspect includes temples, statues, monuments, ghats, parks etc. All of them having been of major public concern should be sufficiently away from landfills.

SITES FURTHER INVESTIGATED

Six sites that appeared more potential for waste disposal were further investigated by drilling up to 8m depth. These include Sanglatar, Bhimdhunga, Satungal, Panga, Bhaktapur-east and Taikabu. Examination of soil profiles and chemical analysis of soil samples for CEC determination revealed sufficient barrier potential at all sites except at Sanglatar where underlying sediments were found to have low CEC values indicating low barrier potential. In view of infrastructure and other relevant criteria sensitive to waste disposal, Taikabu of Bhaktapur (Fig. 4) was found to be the most appropriate site for landfill development and accordingly this was recommended by the DMG. The site is a bowl-shaped natural depression bound by vertical walls from three sides. It is located at about 5 km east of Bhaktapur municipality office. The surrounding walls are composed of sandy to silty sediments on the top and silty to clayey towards bottom. Auger drilling to a depth of 5.25 m at the valley-floor revealed an increase of clay content with high CEC values towards depth. Though the area is a cultivated land, there are only a few small houses around. A motorable road has already reached up to the rim of the depression. The valley has a sufficient capacity to manage the waste of the whole Kathmandu Valley for at least 50 years with adequate space for establishing composting and recycling facilities.

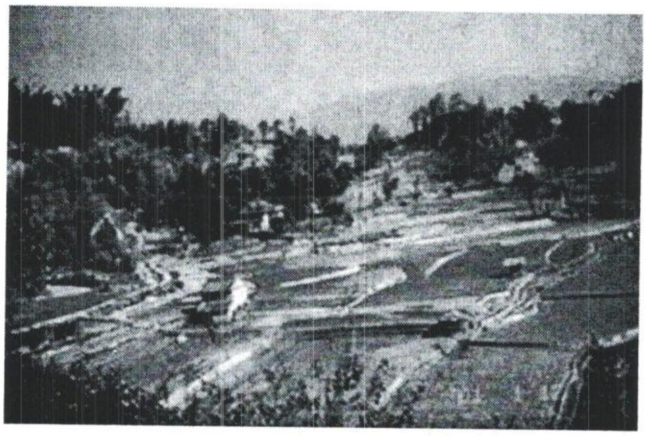


Fig. 4: Proposed landfill site at Taikabu of Bhaktapur.

CONCLUSIONS

The map thus resulting from assessment of barrier potential of sediments in conjunction with other relevant criteria can serve as a very good basis for selection of suitable sites for management of waste in the Kathmandu Valley. However, there still exists lacking of awareness at the planning and decision- making levels about the actual utility of these scientific data for burgeoning problem of safe disposal of municipal waste in want of viable site. Follow-up investigation carried out at selected potential one has distinctly indicated the Taikabu site of Bhaktapur as the most suitable site from all aspects for developing a sanitary landfill for long-term management of urban waste in the valley. The authors as geo-scientist can only advise the concerned authorities to take prompt action towards landfill development in coordination with the related municipalities before it is too late as it often happens due to overlapping interest for competing use of land.

ACKNOWLEDGEMENTS

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