ENGINEERING GEOLOGICAL MAPPING OF DAR ES SALAAM CITY, TANZANIA

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ABSTRACT

Engineering geological mapping of Dar es Salaam city in Tanzania has been carried out using desk studies supplemented by field reconnaissance as well as limited laboratory tests. Desk studies involved interpretation of medium to large-scale topographical maps, Landsat imagery and sequential aerial photographs from 1953-1990. These studies also evaluated small to medium scale geological, pedological maps together with ground water data from 50 boreholes. Two basic maps were prepared, namely, geomorphological and geological maps. The geomorphological map classifies the ground according to slope angles and shows prominent scarps and faults. The geological map depicts the spatial extent of the Neogene geological formations. Three distinct sandstone terraces could be distinguished in Dar es Salaam region at 0 – 15 m, 15 - 30 m and 30 - 40 m above sea level. The terraces comprised sandstones fringed by coral reefs and were backed on their west by uplifted weathered clayey sandstones. Three synoptic construction maps were also prepared:- hazard, resources and land use maps. The hazard map classifies the terrain according to slope steepness, delineates areas susceptible to soil erosion, beach erosion, landslides, flooding, as well as expansive, karstic and saline grounds. The resources map delineates areas with respect to soil fertility as well as the occurrence of sand and gravel, limestone, kaolin, brick clays, heavy minerals and ground water deposits. With respect to light construction of foundations, the middle terrace appeared to be the most suitable in comparison to other terrains.

INTRODUCTION

In expanding metropolitan regions in Europe and Northern America and to a lesser extent developing countries, where geo-hazards are exceptionally severe and resources scarce, engineering geology has been used extensively in long range planning, terrain and ground zoning and the preparation of construction ordinances (Anon 1982, Matula 1979). Nowadays, it is a common practice to undertake geologic investigations of individual sites in certain urban areas in developing countries such as Dar es Salaam (Msindai 1988).

At the time of the present study, Dar es Salaam region, including the city (Fig. 1), a major seaport for Tanzania and six landlocked countries, had a population of about 3.5 million. The rapid population increase and industrial growth demand a concomitant expansion in space for residential areas, urban infrastructure as well as exploitation of earth resources and mitigation of geo-hazards in a sustainable manner. The present study, therefore, attempted to evaluate the individual components of engineering geological units (i.e. rocks, soils, surface and ground water and landscape) in Dar es Salaam region.

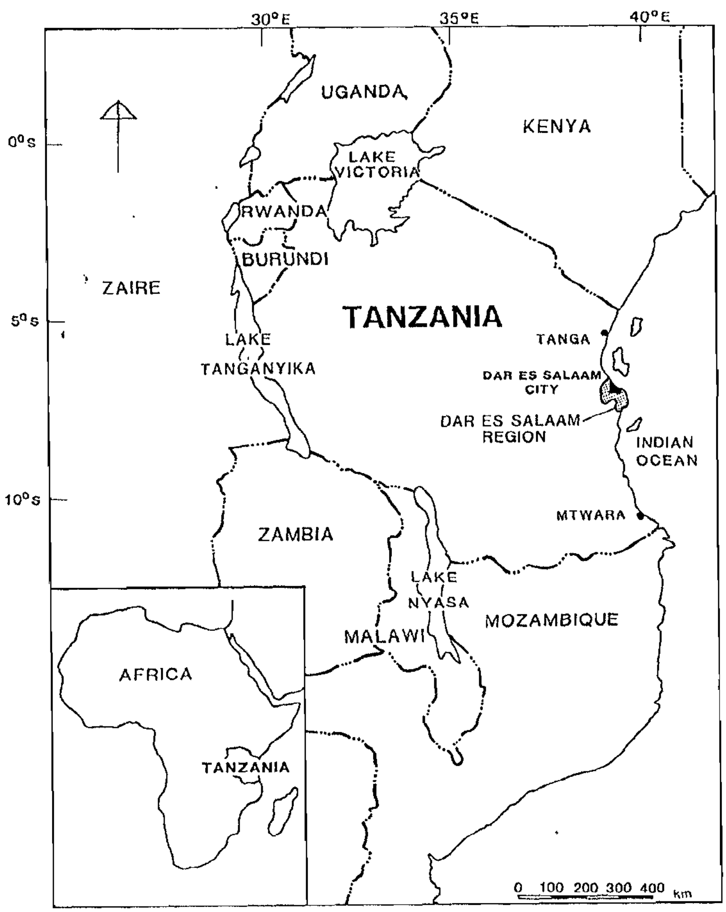

Fig. 1: Location of Dar es Salaam city, Tanzania

Thereafter, evaluation of the geo-hazards and geo-resources was used as a basis for the preparation of a land use map, especially with regard to construction planning of light foundations.

METHODS

Standard techniques for data search, engineering geological mapping and laboratory studies and as described by Gu th (1975), Chaplow (1975) and Matula (1979) were used in the present study. Terrain evaluation involving the evaluation of topographical maps, Landsat imagery and air photographs preceded field reconnaissance (Table 1). Basic engineering geological interpretation techniques of black and white aerial photographs and Landsat imagery were modified to suit local conditions. Several primary attributes such as landform, soils and bedrock types were synthesized together with subtle secondary attributes such as the engineering properties of soils, rocks and ground water conditions. Field traverses consisted of two 40 —60 km longitudinal profiles parallel to the coastline (Fig. 2). In addition, five short 10 — 15 km west to east transverse profiles for the central and northernareas were carried out. In the field emphasis was placed on feature observation, documentation and sampling. The significant observations included soil types, ground features, foundation considerations, surface and ground waters, environmental aspects, faults and ground zoning. Twenty-nine sampling localities for soils and rocks comprised pits, trenches, cliffs, quarry faces and road cuts. The studied material comprised ten carbonate and calcareous sandstones, fourteen upland sandstones and terrace sandstones and twenty-six soils. Basic and classification properties of soils and rock masses were determined from disturbed and highly weathered rocks using the British Standard. The results of laboratory tests have been described elsewhere by the author (Msindai 1988).

Every information located was assessed for its relevance, reliability and stored for later incorporation. The type and amount of information acquired during these investigations is shown on Table 1. This information included the city infrastructure, morphology, geology, geo-hazards, geo-resources and land use.

Table 1: Sources of data as well as information derived from desk studies on Dar es Salaam Region, Tanzania

Type and source of data	Quantity	Nature of information
Topographical maps (Survey and Mapping Division) Scale 1:50 000 1:25 000 1:10 000 1: 2 500	16 pcs	Interpretation of morphology, Indirect information on ground conditions, hazards, resources and land use
Geological map (Bartholomew 1963, Moore 1963, Anon 1979c)	3pc	Geology
Aerial photographs (Survey and Mapping Division) 1953 series 1:40 000 1961 series 1:60 000 1981 series 1:50 000 1981 series 1:12 500	60 pcs	Morphology, lithology, hazards, resources and land use.
Landsat imagery	1pc	
Ground water drill holes (Ministry of Water) (Anon 1979b)	50 pcs	Lithology, aquifer and ground water conditions
Pedological map (Anon 1979c)	1pc	Lithology, morphology, soils.
Land use maps (Survey and Mapping Division) (Temple 1970, Anon 1979a&c) Scale 1:125 000 1:500 000	3 pcs	Past and present regional and city land use. Geomorphology.

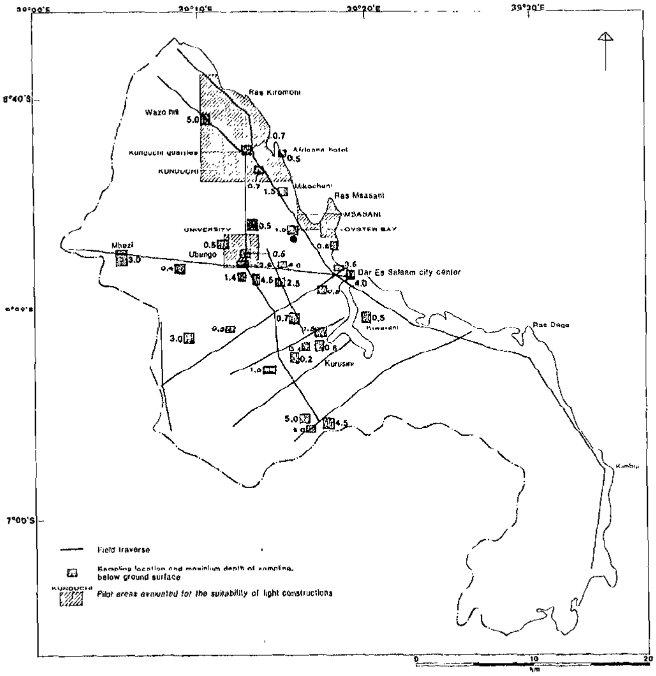

Fig. 2: Investigation map of Dar es Salaam region, Tanzania

RESULTS

A variety of special and multipurpose synoptic maps have been prepared for regional and city master planning, and these are geomorphological, geological, geo-hazard, geo-resources and land use maps. Engineering geological mapping as used here refers to the identification and separation of ground hazards, earth resources and their combinations into uniform zones. Very intense geo-hazards as well as large reserves of earth resources, limit the use of ground for construction of city infrastructure. In addition, an attempt has also been made to semi-quantify the intensity of each factor that limit, hinder or favour construction of light foundations.

Geomorphological map

The engineering geomorphological map shows the division of the terrain in Dar es Salaam region as having three classes of slope angles, namely 0 —5%, 5 —15 % and >15 % (Fig. 3). With reference to morphologicalconditions, the most flat lying terrains (i.e. slope angles <5%) are confined on the terraces and to a lesser extent the uplands. However, certain locations with moderate slopes (i.e. 5 —15 %) occur on the uplands in the southern and western parts of the city center.

Three distinct terraces can be distinguished in Dar es salaam region (Fig. 3). The lowermost terrace, Mtoni is elevated at 0 —15 m, the middle terrace, Tanga at 15 - 30 m and the highest terrace at 30 - 40 m above sea level. The city shows a wide variety of residual and transported soils on the sedimentary bedrock. Coarse-grained soils are most widespread within the coastal terraces. Fine-grained soils and expansive clays interbed with coarse grain soils are restricted within the valleys. Salinas are confined within the supratidal and inland evaporite depressions. Laterites, terra rossa and weathered upland clayey sandstone are restricted to the upper terraces and upland areas.

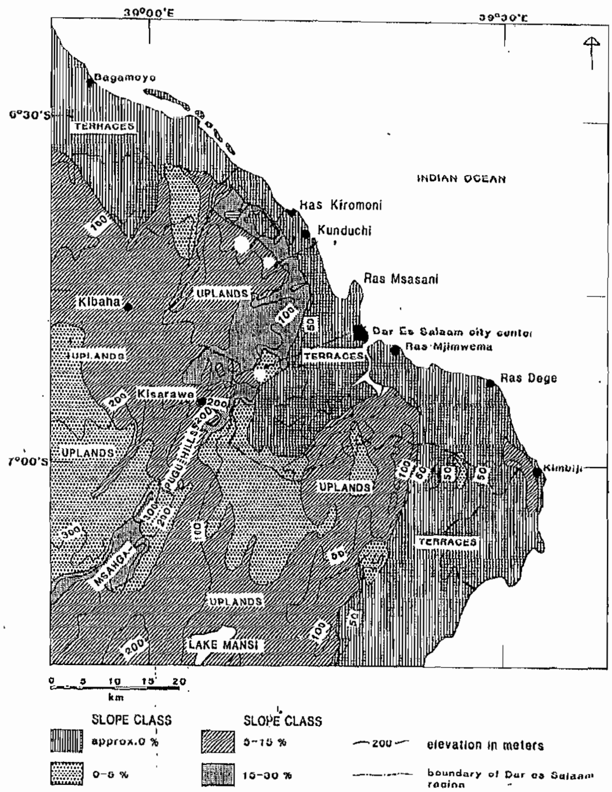

Fig. 3. Geomorphological map of Dar es Salaam region, Tanzania

Within the terraces, the creeks are U-shaped. Towards the west, the upland sandstones form an uplifted fault block. It is elevated at about 40 —200 m above sea level. West of Kunduchi, there occurs restricted flat lying terrains at the eastern edges of uplands. The highest peak, at 234 m above sea level lies on another fault block, the Pugu hills. Valleys within Pugu kaolinitic sandstones are V-shaped.

Geological map

The engineering geological map variant (Fig. 4) shows the distribution of Neogene formations. It is of medium scale and thus allows subdivisions of the terrace and upland formations. Sandstones and carbonate rocks are two dominant groups of rocks that typify the Dar es Salaam region. Within and between these groups, several distinct varieties are recognizable. Sandstones occupy over three quarters of the region and comprise seven main types. The massive terrace sandstone is the bedrock that limits the extent of terraces. Aerially, it is more extensive on the central and southeastern parts of Dar es Salaam region. It is however, narrowly developed beyond 5 km in the northwest direction of the city center.

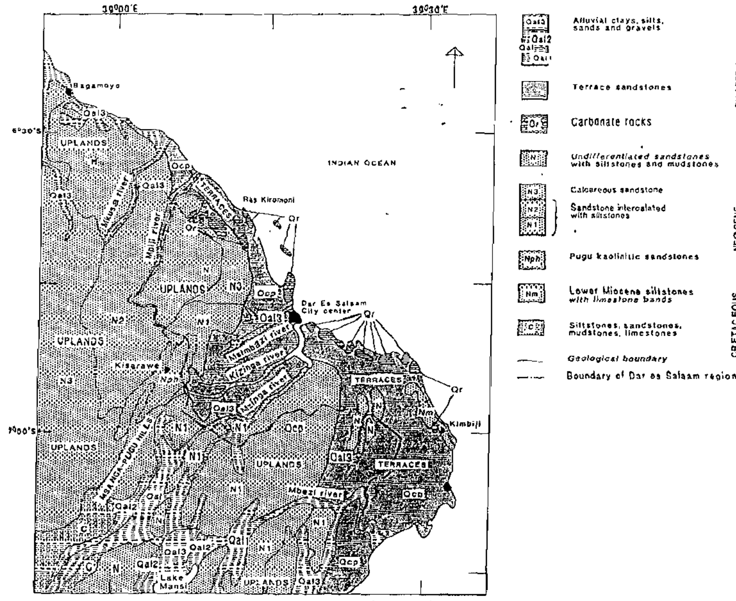

Fig. 4. Geological map of Dar es Salaam region, Tanzania (after Bartholomew 1963, Moore 1963, Anon 1979c)

The Pugu sandstones comprise three units; massive, kaolinitic and cross-bedded sandstones (Fig. 4). Medium sandstones form a large part of the western part of the uplands. A 10 km long and 1 —3km strip of siltstones form part of the Kimbiji embayment. This stretch of bedrock is however intercalated with 2 —4 m bands of carbonate rocks. On the central western border, 8 km long, 3 km wide and 30 m thick sandstone area that is predominantly kaolinitic occurs. Calcareous sandstones also occur on back reef areas of uplands.

Two largest occurrences of carbonate rocks are found as fringing reefs and raised reefs. In comparison to the southern coastline, the northern part of the region has few fringing reefs. In addition, three raised reefs, with a mean thickness of 10 m, dominate the eastern margins of uplands.

Geo-hazard map

Spatial planning requires that hazards that limit foundation planning are identified and semi-quantified. The classes of slope with respect to other hazards have been ranked into three intensity scales and coded into a three-digit matrix. The intensity of each hazard is also symbolically portrayed in small and capital letter notations. Furthermore, the resultant hazard map divides the region into three degrees of intensity (Fig. 5).

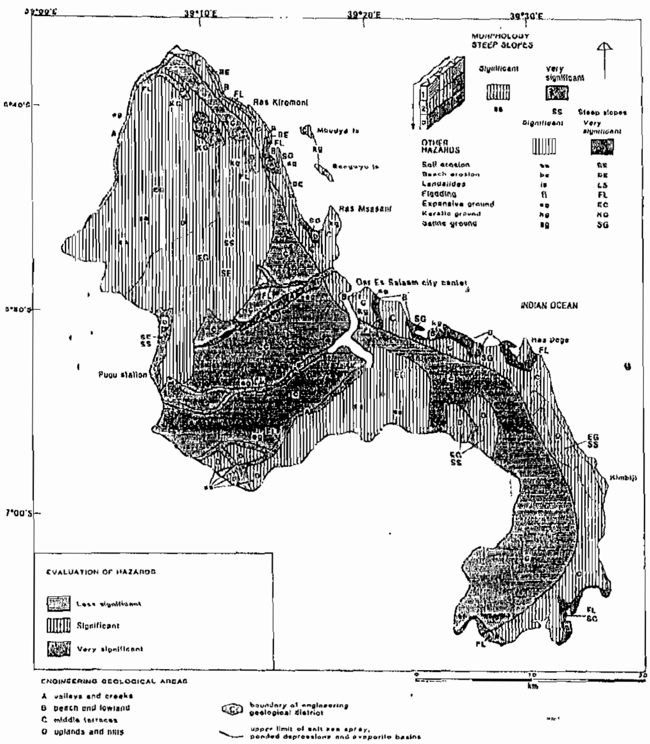

Fig. 5. Geo-hazard map of Dar es Salaam region, Tanzania

Mass movements (i.e. soil erosion, creep and landslides) dominate the upland steeper grounds and therefore are a negative phenomenon in foundation planning. In addition, areas that are susceptible to shrink-swell phenomena are quite common on upland areas. It is also shown that the narrow coastal terraces are not only prone to salt corrosion but also intense beach erosion, karstification and flooding.

Two largest occurrences of carbonate rocks are found as fringing reefs and raised reefs. In comparison to the southern coastline, the northern part of the region has few fringing reefs. In addition, three raised reefs, with a mean thickness of 10 m dominate the eastern margins of uplands. These carbonate units are frequently karstified with numerous underground openings of varying sizes from 0.5 — 10 m^2.

Geo-resources map

The geo-resources map depicts the locations of earth resources within the region. As with the geo-hazard map, geo-resorces are displayed and depicted into three degrees of reserves (Fig. 6). The soil fertility has been classified into a three-digit matrix with respect to other earth resources. Fertile ground is mostly located within the creeks and upland whereas aquifers are located on the terraces and foot scarps of western margins at Pugu hills. Sands are extensively developed on the lower and middle terraces. Sands of better quality are exploited within the river valleys. Aerially, it is more extensive on the central and southeastern parts of Dar es Salaam region. Other earth resources shown on the maps are limestones, clays for bricks and kaolin. Only the sands and limestones are mined at large quantities and their exploitation and lack of mitigation measures have attracted much attention.

Land use map

The land use map is basically an environmental geological map (Fig. 7). It semi-quantitatively sums up the spatial interrelation between geo-hazards and geo-resources, and therefore facilitates in city master planning of suitable grounds for light constructions and transportation corridors. The lowest terrace is the most dynamic engineering geological area in Dar es Salaam region (Temple 1970). Along the coast, north of the city, beach recession of up to 7 meters per year is common (Msindai 1988). Furthermore, the presence of saline, dunes, rock falls and shallow water table in these areas are the dominant hindrances. It should also be noted that appreciable aquifers and heavy mineral sands occur close to the coastline. The yield of wells within sand dunes and beach deposits is on the average less than 400 m^3/day (Anon 1979a, b).

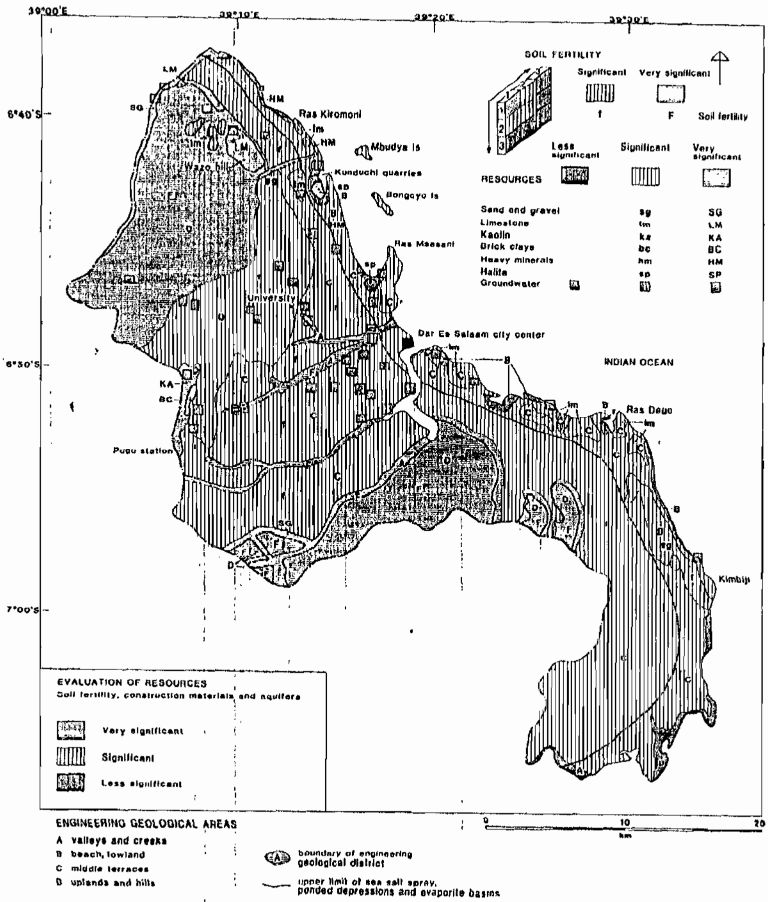

Fig. 6. Geo-resources map of Dar es Salaam region, Tanzania.

Nevertheless, in several localities, ground water wells have been affected by seawater intrusion and effluents from septic tanks. Quite commonly, shallow ground, water table, flooding and salty ground periodically result in flooding basements and septic tanks, differential settlement of road embankments and corrosion of road aggregates within the lowest terrace.

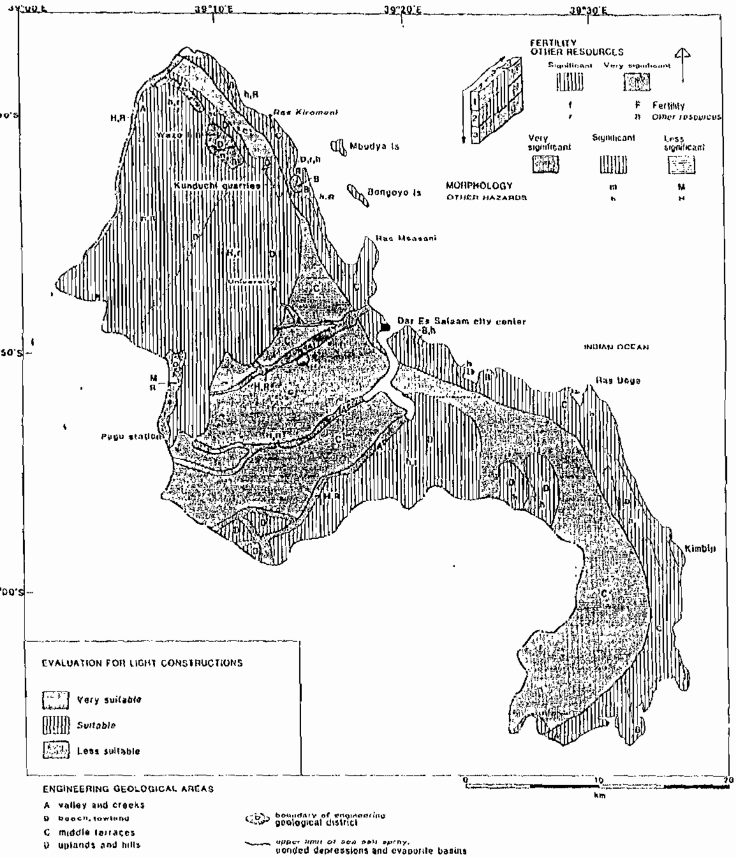

Fig. 7: Land use map showing the suitability of the grounds for light construction in Dar es Salaam region, Tanzania

The middle terraces possess the least resources and excellent bearing capacity. The groundwater table at these localities is more than 20 m deep. Although, appreciable limestone deposits occur south of the city center, the quality of their aggregates is poor due to the highly weathered state, which has been accentuated by sea salt spray. On uplands, earth resources are restricted to Wazo Hill, Kunduchi and Pugu Hills. In addition, extensive abandoned quarries and sand pits typify some parts of this terrain especially the Wazo Hill and Kunduchi areas. Within the rest of the uplands, suitable ground, for foundation works is limited to narrow ridges, which are often pseudo-karstic, highly weathered or expansive. It should be noted that the seasonal fluctuation of groundwater table on highly expansive ground enhances differential movement. At the same time the creep phenomenon is commonly observed along very steep slopes on uplands. Very suitable grounds for foundation planning of light construction are situated within all engineering areas of Dar es Salaam region, however, the extensive areas with excellent ground bearing capacity are limited within the middle terrace sandstones. With respect to the foundation planning against hazards, these are confined within valleys and a narrow belt parallel to the coastline.

The present investigations have enabled a fair portrayal of the engineering geological setting of Dar es Salaam region. Desk studies and field mapping have facilitated in evaluation and mapping of geo-hazards, and geo-resources (Fig. 5 and 6). This information has been used to produce a land use map and assessment of suitability of foundations for light construction (Fig. 7).

For construction purposes, Dar es Salaam region has been subdivided into four engineering geological areas:- the uplands, the upper coastal terrace, the lower coastal terrace, and the valleys and creeks (Fig. 7). Very suitable grounds that demand minimal foundation requirements are situated on the upper terrace sandstones and upland sandstones where the overburden is > 2 m and slope angles < 5 %. Suitable grounds for construction that require precautions against underground defects, shrink-swell effects and shallow ground water table are located within depressions on the upper terraces, limestone terrains and upland sandstones where slope angles vary from 5 — 15 %, and ground water table < 2.5 m. Suitable ground that need utmost design considerations against geo-hazards such as flooding, corrosion, quick sands, landslides and soft clays are situated on seasonally flooded areas, creeks, valleys, intertidal areas, lowest terrace and saline ground.

Matula (1979) has stressed the need for mapping and zoning in systematic regional studies, the classification of collected data on engineering geological environments and their individual components. Engineering geological mapping and zoning provides a model base for generalizing and by analogy transmitting experience on rock behaviour, on efficient investigation methods in similar zoning units. The present finding embodies the initial philosophy in mapping, zoning and typification of foundation conditions that may lead to cost-efficient estimation of foundation works. Finally, it aims at the use of information systems in regional engineering geological studies.

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