# *Geological constraints on urban sustainability, Kinshasa City, Democratic Republic of Congo*

**A. S. A. Lateef, Max Fernandez-Alonso, Luc Tack, and Damien Delvaux**


## ABSTRACT

Kinshasa City, the capital of the Democratic Republic of Congo, is a case of an aborted urban development. Natural phenomena combined with political instability, collapse of state, and civil strife blurred further the inherited infantile urban character of colonial times to yield an urban morphogenetic crisis. In this article, we use surface and subsurface geological data in the form of several geological and hydrogeological maps, groundwater contour maps, geotechnical isopach and isohypse maps, and other illustrations that aid in the recognition of problems of pollution, accelerated erosion, and floods to highlight the geological constraints on sustainable urban planning, socio-urban setting, and human well being in this African megacity.


## INTRODUCTION

### General Statement

Geological conditions of the terrain and finite earth resources are key factors in urban sustainability of all large cities. However, direct experience in many developing countries shows that geological information is not appropriately considered in urban planning. In this article, we highlight the role of geologic knowledge in sustainable urbanism.

Urban development of Kinshasa City has certain characteristic features.

- The city lacks long urban development. Over a time span of merely one century, the city developed from a rural-tribal sparse society into an ill-managed megacity. The limited preindependence urbanization features degraded and were replaced by chaotic growth because of political instability, collapse of state, and civil strife.


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- The steady rural exodus acted as a social diluting agent to the fragile and young preindependence urban social fabric. It is an observable phenomenon in Kinshasa that rural and urban characters intermingle and form a single social field or organization. Town and village form a well-recognized dichotomy. Slums, disconnected from any economic growth, encroached on the city. This explains the difficulty of applying classical urban theories and procedures to Kinshasa City (see, e.g., De Boeck, 2006).

Although the physical conditions of urban geology seem, at first sight, independent of these chaotic sociopolitical conditions, they do bear the effects through the deterioration of the geoenvironment and exhaustion of natural resources.

The purpose of this contribution is to present an overview of the existing geoscience knowledge on Kinshasa City applicable to future urban planning and environmental protection. This introductory geological work provides, hopefully, indicators for planners, engineers, environmentalists, and decision makers to tackle the encroaching urgent issues of impaired water quality, soil erosion susceptibility, and floods. This work also offers methodologies and approaches that serve as prototypes for future urban research in the Democratic Republic of Congo. The study uses surface and subsurface geological data that have been obtained by many geologists during the 20th century. Early data sets embody some inadequacies and ambiguities that should be considered as one goes through the results of this work.

### Location

Kinshasa City is located on the left bank of the Congo River where the watercourse draws a wide crescent-circular pool: the Malebo Pool (Figure 1).

The city lies between 4°17′30″ and 4°30′00″ latitude south and 15°12′ and 15°30′ longitude east. It is bound north and west by the Congo River, which is also the border with the Popular Republic of Congo (Brazzaville), east and northeast by the Bandundu Province, and south by the Bas Congo Province.

### Brief History of the City

Archaeological findings indicate early man (late Acheulian and lower Paleolithic) presence in the Kinshasa plain (van Moorsel, 1968). During the last few centuries, the locality was part of the Kongo Kingdom. In the 19th century, the site was inhabited by natives living in large fishing and trading villages. One of these villages had the name Kinshasa.

Later in that century, the navigation of the Congo River by Henry M. Stanley in 1877 led to the establishment of an inland trading river port in December 1881. The post was named Léopoldville, after the name of the King of Belgium. At the time of its foundation, Léopoldville occupied the present-day Mont Ngaliema as an almost western mirror image of Kinshasa Village. In 1885, the Berlin Conference

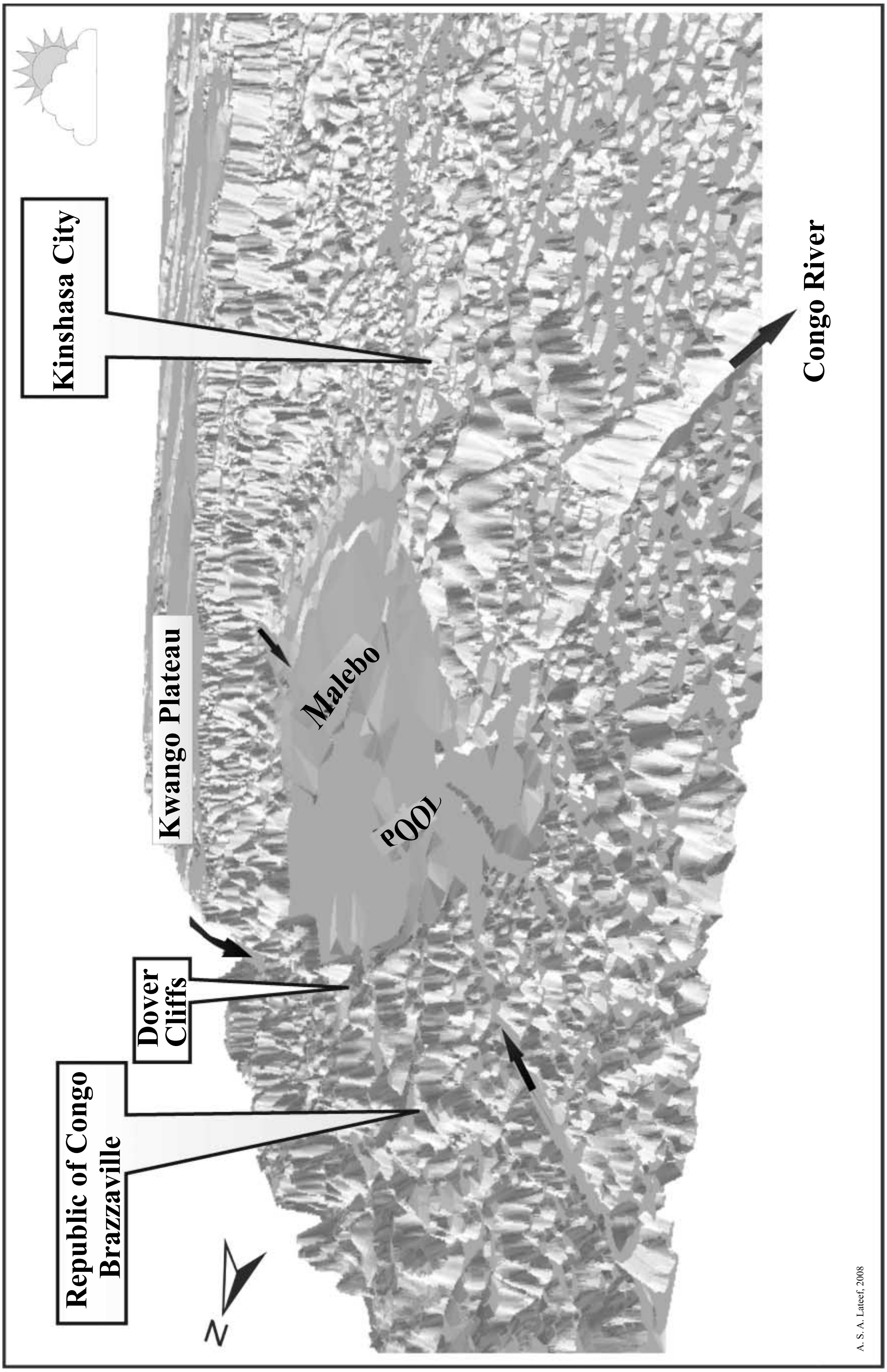


**Figure 1.** Three-dimensional surface visualization of Kinshasa City. Vertical exaggeration: 10.

acknowledged the Belgian royal role in the Congo, giving rise to the Congo Free State. The presence of rapids or cataracts between the mouth of the Congo River on the Atlantic and the newly established trading post made the river innavigable. This feature of the Congo River course handicapped transportation to and from Léopoldville. The construction of the Matadi railroad in 1889–1898 under the direction of General Albert Thys with native and expatriate manpower overcame this obstacle. This important event led eventually to the transformation of the small Léopoldville trading post into a city. In 1923, Léopoldville replaced the seaside town of Boma as the capital of the Belgian Congo. The name Léopoldville remained in use from 1881 to 1966. After that, the capital took the current name Kinshasa.

## Area and Population

Kinshasa Province has an area of 9965 km$^2$ (3847 mi$^2$). However, the city itself or the urbanized part is much smaller. At present, the urbanized area of the city is around 650 km$^2$ (251 mi$^2$) compared to 600 km$^2$ (232 mi$^2$) in 1985, 134 km$^2$ (52 mi$^2$) in 1955, and 20 km$^2$ (8 mi$^2$) in 1950. There has been a general steady growth of population and spatial expansion. However, two periods were marked by notable high growth rates of population: the first was between 1941 and 1948, a period during which the population of Kinshasa tripled as a result of economic prosperity during and after the 2nd World War. The second surge of population occurred after the independence in 1960.

Population growth and spatial occupation in Kinshasa do not show a coincident and parallel development. Most of the Kinois population is very young, as can be expected from the low life expectancy of 53.29 yr and the high population growth rate of 3.39 (high fertility). More than half of the population is less than 20 yr of age. Some reports indicate that today, half of the Kinshasa population is below 15 yr of age. Birth rate is higher in Kinshasa (51.1 per 1000) than in other parts of the Congo (48.1 per 1000). This is in conjunction with a lower mortality rate compared to other Congolese cities.

## Socio-urban Setting

In the early colonial period, the small Léopoldville City had clear-cut ethnic-urban divisions: (1) northern European zone where administration, commerce, and industry were concentrated (Europeans also had residence villas on Ngaliema hill and the south and southwestern hills of Binza and Djelo); (2) narrow transition or buffer zone occupied by Portuguese who were small business merchants; and (3) southern zone destined for natives who provided the manpower and who lived in planned residence quarters called "cités indigénes."

At present, the city is made up of 24 communes divisible into three socio-urban zones.

1. The "Ville" or "Centre Ville" with an inherited European style of urbanization. This is the area where in colonial times the colonizer lived and worked, and is today the privileged sector where the elite lives. It is also the commercial and administrative heart of the town. It extends from Ngaliema hill in the west to the Malebo Pool in the east. The Congo River is the northern boundary. This area is traversed, in the east–west direction, by the main city artery: the Boulevard du 30 juin. The Ville includes the communes of Gombe, Barumbu, Kinshasa, and Lingwala in addition to the northern tips of the Bandalungua and Kintambo communes.
2. The "Cité" or the popular area. It is located south of the Ville and comprises the biggest part of Kinshasa where the larger part of Kinois, with low income, lives. It bears all the elements of native culture, art, and cuisine. It is separated from the northern rich center by the green-governmental and industrial belt. The main artery of this zone is Avenue Kasa-Vubu, which runs north–south to southwest direction. Originally, at colonial times, the "cités indigenes" that occupied this zone were planned living quarters. However, later, this zone degraded to a situation of shantytowns. Administratively, the zone covers the communes of Bandalungwa, Kintambo (except northern tips), Ngaliema, Selembao, Bumbu, Ngiri-Ngiri, Kasa-Vubu, Kalamu, Makala, Lemba, Ngaba, Limete, Matete, and Masina.
3. The third socio-urban zone of Kinshasa is the "cités périphériques," "communes urbano-rurales," or shantytowns and slums. These occupy wide areas on the southern hills and the eastern plain and extend over the communes of Mont Ngafula, Kinsenso Ndjili, Kimbanseke, and Nsele. They are a symbol for the unplanned chaotic spatial growth of Kinshasa. They lack basic infrastructure and urban services. Here, large numbers of Kinois live out of the formal urban Kinshasa. For further details, the reader is referred particularly to the comprehensive atlas of Kinshasa (Flouriot et al., 1978).

## URBAN GEOLOGY

### Climate and Vegetation

The climate is tropical soudanian (Robert, 1946; Devroey and Vanderlinden, 1951) or soudano-guinean (Aw4 Köppen climate).

The city has two principal seasons: a wet season that extends from October to May with warm temperatures (25.6°C) and a dry season that extends from June to September with slightly cooler temperatures (22.8°C). The slight temperature difference between seasons indicates a relative isotherm climate. A drier spell (15 days) has been recorded within the wet season (end of December). The average relative humidity is 79% (between 71% minimum and 84% or higher maximum). The annual average rainfall is 1529 mm (60 in.) (with a minimum of 1222 mm [48 in.] and a maximum of 1863 mm [73 in.]). Heavy torrential rains occur in November immediately after the dry season as well as in March and April.

Grassy vegetation develops. Soil type and humidity conditions permit the growth of typical bush-savanna (grassy xerophil species) and oily treelike vegetation (e.g., *Annona*, *Hmenocardia*, *Psorospermum*, *Gaertnera*, *Sarcocephalus*, *Crossopteryx*, *Brideli*, and *Bauhinia*) (Robyns, 1950; Delevoy, 1951). Gallery-scanty forests do exist along streams and watercourses (epiphytes and creepers).

### Geomorphological Setting

The city is located on the Malebo Pool. This pool has a circular, although slightly asymmetrical, form where the Congo River (water level at ~298 m [978 ft] above sea level [a.s.l.]) broadens into an internal lake having a diameter of approximately 25 km (15 mi). On the southern bank of the pool, where Kinshasa City is located, the altitude of the city plain ranges between 300 and 350 m (984 and 1148 ft).

Four macrogeomorphologic zones can be recognized in the Kinshasa City region: (1) the southern hills zone, (2) the gently undulating plain of Kinshasa City proper, (3) the eastern plain, and (4) the flood basin. These zones are depicted in Figure 2.

East of Kinshasa City proper, the Kwango Plateau stands very distinct as a table-land.

The indicated geomorphologic zones are bounded from the east by the prominent Kwango Plateau (~700 m [2296 ft]) and from the west by gentle slopes that lead first to an altitude of 500 m (1640 ft) then to the vast plateau of cataracts or rapids (600 to 800 m [1968 to 2625 ft]). On the south, above the steep slopes, the hill zone shows a progressive increase of relief from 350 to 500 m (1148 to 1640 ft).

On a larger scale, the landscape of the city also reflects small-scale geomorphologic phenomena and microrelief features that are beyond the scope of this article.

### Geological Setting

The Kinshasa region is located on the eastern fringe of the Pan-African west Congo belt. Based on the geological reconstructions of Tack et al. (2001) and Frimmel et al. (2006), it appears that from a tectonostratigraphic point of view, the Kinshasa region is part of a foreland basin that postdates the Pan-African orogeny. The few folds and faulted folds (Schisto-Calcaire sequence) south-southwest of the Kinshasa Province (e.g., Bamba Kilenda locality) plunge, in the Kinshasa region, beneath undeformed gently northeast-dipping Inkisi siliciclastics and overlaying younger continental sediments.

The geological setting of Kinshasa City has developed in a transitional area between two geologically contrasting domains:

- To the west, down Mount Ngaliema and farther downstream the pool, subhorizontal, gently northeast-dipping red bed facies siliciclastic sedimentary rocks of the Inkisi Group (Frimmel et al., 2006), known as the Kinsuka arkoses, start outcropping and impose the first rapids or cataracts to the Congo River. From there, the river flows in a southwest-trending, approximately 500-m (1640-ft)-wide gorge, cut in the Inkisi red beds. The rocks display a prominent, subvertical, conjugate northeast- and northwest-trending jointing. They are unconformably overlain by generally poorly consolidated, although in places cemented, Upper Cretaceous sandstones, Kwango series (Ladmirant, 1964; Lepersonne, 1974), forming a range of rather flat-topped hills (~500 m [1640 ft]), with gently graded interstream tracts and broad inactive valley floors (De Ploey, 1968; Van Caillie, 1987).
- To the east, near the locality of Maluku and upstream of the pool, the exposed section consists (from the bottom to the top) of Cretaceous white sands (Kwango series), commonly consolidated and forming along the northeasternmost part of the pool, the so-called Dover Cliffs (Dadet, 1966). These sandstones are overlain by the Cenozoic Kalahari sequences, including

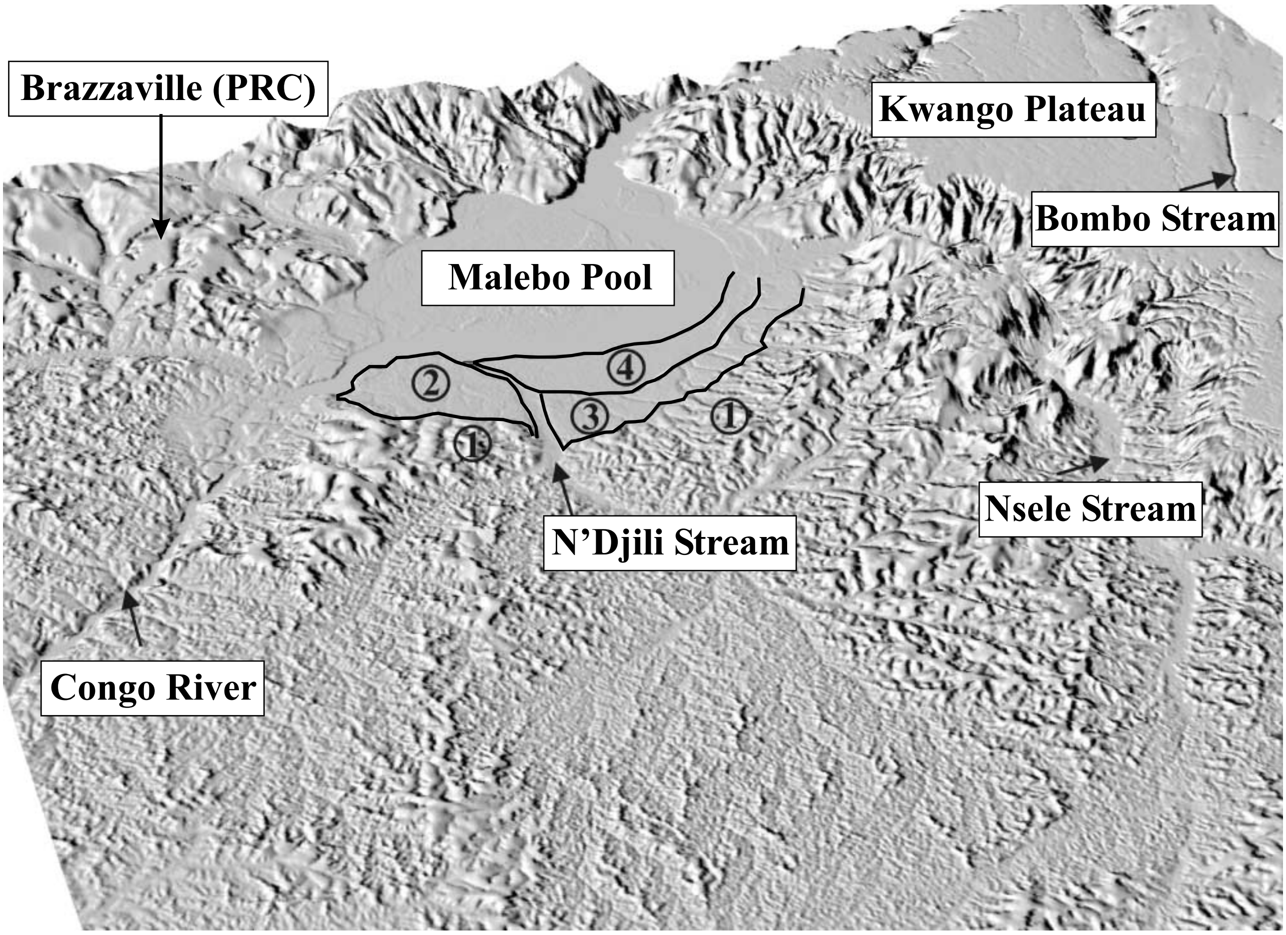


**Figure 2.** Medium-resolution (90 m [295 ft]) shuttle radar topography mission-based digital elevation model (SRTM DEM) (3 arc seconds) showing the physiographical setting of Kinshasa City and its environs. See text for explanation. PRC = People's Republic of Congo.

Paleogene sands, locally strongly silicified into slabs of orthoquartzites (Grès Polymorphes), covered by Neogene loose sands (Sables Ocre). The latter form the flat, approximately 700-m (2296-ft)-high Kwango Plateau displaying an outstanding microrelief.

The general geological setting of the city is shown in Figure 3. For more regional geological features, the reader is referred to the Léopoldville quadrangle map.

## Local Stratigraphy

The stratigraphy of the Kinshasa region has been developed more than 50 yr ago (see, e.g., Mathieu, 1912; Lepersonne, 1937; Corin and Huge, 1948; Cahen, 1954; Egoroff, 1956; Sekirsky, 1956). No stratigraphical revision or ages have been introduced during the last five decades. One should thus be aware of the constraints on the level of knowledge, but this is not the topic here.

All deposits are continental of fluvial, fluviodeltaic, fluviolacustrine, lacustrine, and eolian genesis. The documented stratigraphy of Kinshasa extends from the late Precambrian to the Holocene with numerous unconformities of various magnitudes. The lithostratigraphy of Kinshasa City is given in Figure 4. It constitutes part of the stratigraphy of the larger Kinshasa Province.

Except for the marly sandstone unit that overlays the Inkisi siliciclastics, the pile of continental deposits lack independent dating. The spatial and temporal stratigraphical relationship of the Neogene units is commonly unclear or ambiguous.

## Water Resources

### General Statement

With abundant rainfall and the presence of the Congo River and tributary streams, Kinshasa City has plenty of water resources. However, the availability of safe

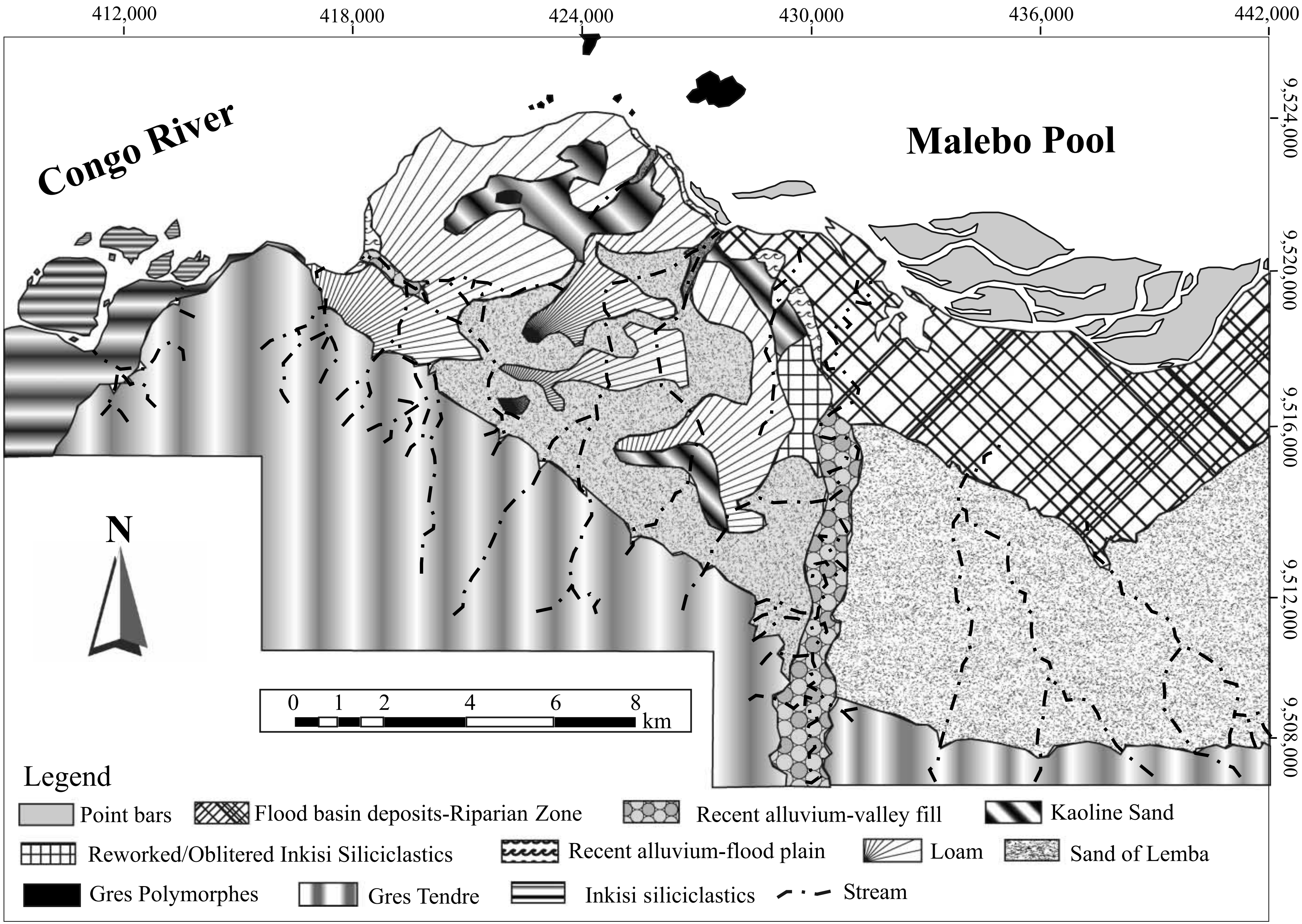


**Figure 3.** Geologic map of Kinshasa City (modified from Egoroff, 1956).

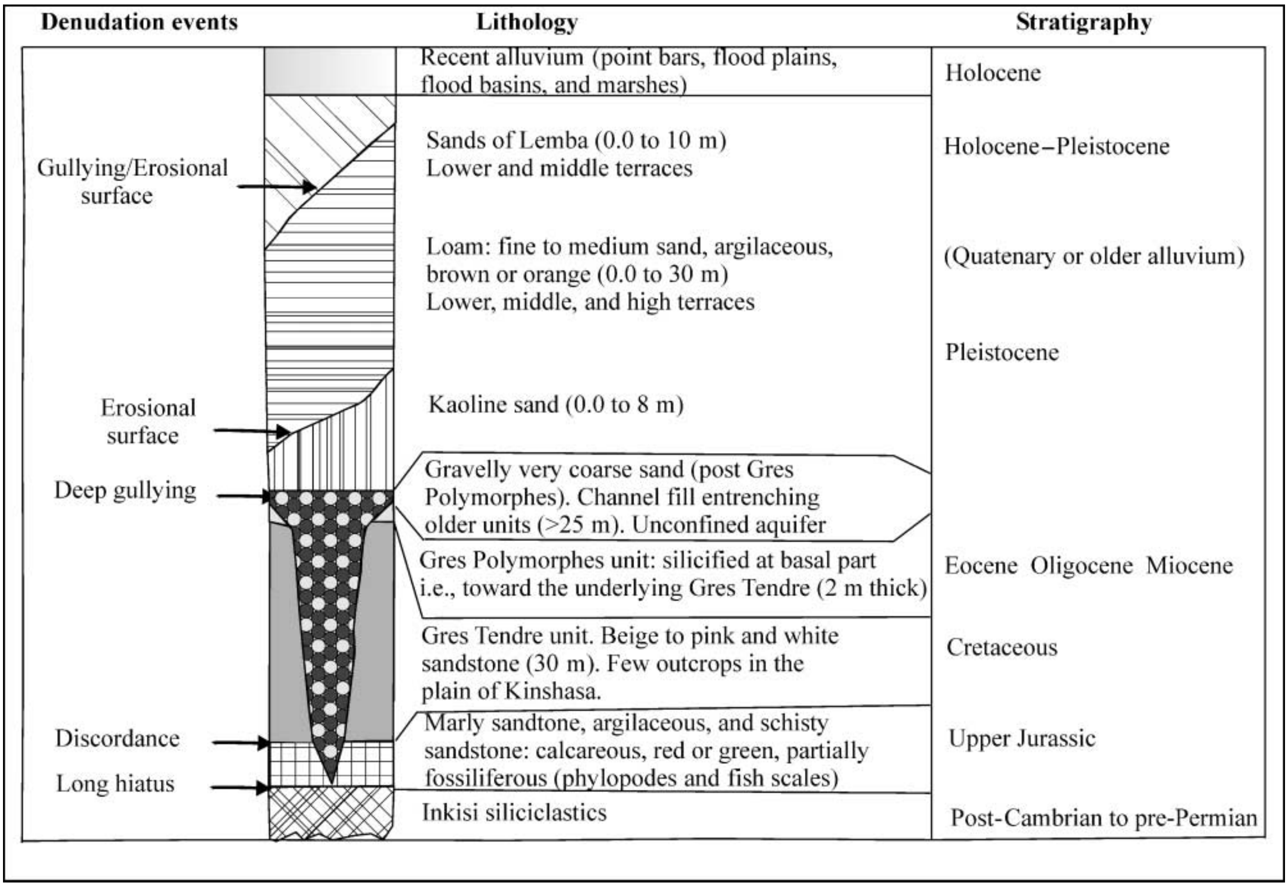


**Figure 4.** Local stratigraphy of Kinshasa City.

drinking water is a challenge to the population. This paradoxical situation is clearly illustrated by Mwacan and Trefon's (2004) statement that the water in Kinshasa is rare like it is in the Sahara. Insufficient water supply for the Kinois family has serious health consequences and adds a heavy burden on women who are responsible of the family affairs (J. Mukenyikalala, 2007, personal communication). Because of this shortage in water supply, it is not unusual to see women and men carrying large vats of water to their homes.

The spatial growth of the city without a parallel development of treatment and distribution infrastructure made these inadequacies more apparent and more annoying in the everyday life of the citizens. At times, in the past, the authorities tried to use trucks and tankers to distribute drinking water in areas where the water distribution network does not exist but this, also, did not continue because of financial and maintenance obstacles. Until today, potable water production is based on surface water resources, river, and streams. The sole organ responsible for the distribution of drinking water in Kinshasa City is the "Régie des Eaux" or better known as "REGIDESO." Up to 1960, the REGIDESO was doing satisfactorily. The situation started to deteriorate after 1960. Currently, the REGIDESO has three installations: one on the N'Djili stream, another on the Lukunga stream, and the third on the Congo River. The availability of surface waters did not call for effective exploitation of groundwater resources.

Insufficiency of production and lack of distribution networks in many parts of the city, particularly in the peripheral communes, should bring attention to groundwater resources. This aspect is covered in the following subsections.

### Hydrogeology of Kinshasa City

The hydrogeology of Kinshasa city is mostly that of an unconfined aquifer system hosted mostly in the unconsolidated sediment cover. In such a system, environmental issues are of great concern. The shallow water-table aquifer interacts and communicates with both the deeper free aquifers and with human activities and water bodies on the surface (streams, Congo River, and swamps). Therefore, a study of the shallow aquifer is

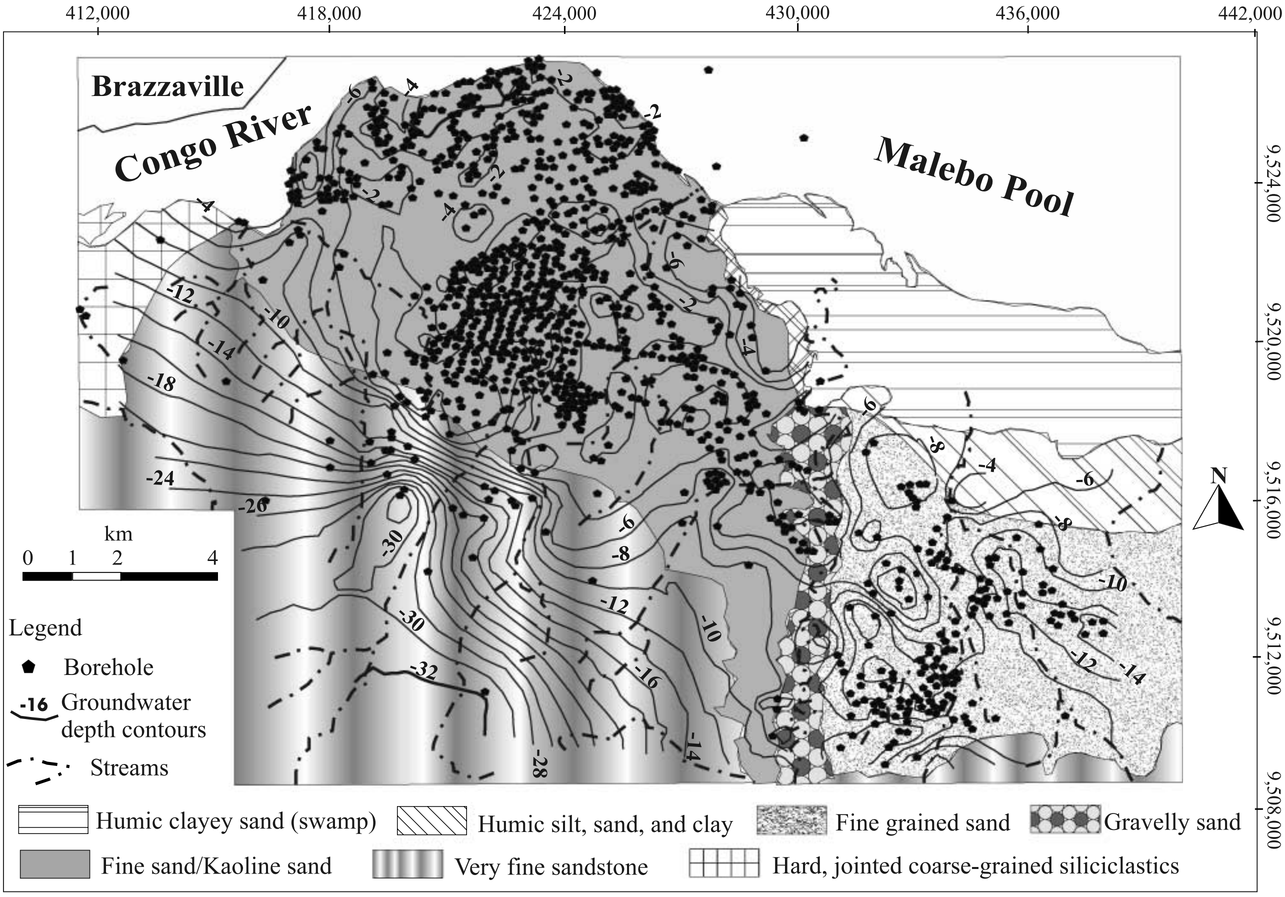


**Figure 5.** Hydrogeologic map of Kinshasa City indicating the main hydrogeologic units, groundwater depth contours, and the location of 1270 boreholes.

not only important for water harvesting but also for antipollution and sanitation policies.

The hydrogeologic map of Kinshasa (Figure 5) was compiled incorporating borehole location data of Van Caillie (1977–1978).

Data from hundreds of boreholes, indicated in Figure 5, have been used to construct water-table groundwater contour maps for Kinshasa City (Figures 6, 7). Fewer borehole data come from the hilly zone, hence the extrapolations to the south should be regarded with caution. Flow rate is related to porosity and permeability of the type lithology. Flow directions are related to drainage system, topography, rainfall intensity, and type of sediments.

These constructions suggest the irregularity of the static surface depth of the aquifer with a general deepening toward the southern hilly area. Recharge to the unconfined aquifers is from precipitation on the catchment area and its subwatersheds, in the interstream zones, by downward percolation through the porous loose fine sands and silts. The presence and amount of argillaceous and clayey component in the clastic deposits makes infiltration and recharge variable from place to place.

Discharge of the water-table aquifer occurs as seepage through springs, swamps, and streams.

The water-table aquifer overlays other unconfined aquifers. Examination of Figure 4 shows that, at the level of the top "Grès Polymorphes" and "Grès Tendre" units, buried gullies have entrenched, at places, deep enough to downcut the Inkisi siliciclastics. These buried channels have a coarse-grained clastic-gravelly fill. This fill is an important hydrogeologic unit. It represents a relatively deep aquifer with a characteristic high yield. Overlaying the gullied sequence is a layer of Kaoline sand (0 to 8 m [0 to 26 ft] thick). The Kaoline sands, spatially and in exposure, occupy low-lying parts of the undulating terrain of the Kinshasa plain. Temporally, the unit is affected, at the top, by limited dissection. Hydrogeologically, this unit has low hydraulic conductivity. It acts as an aquitard. The presence of these Kaoline sands and other more argillaceous beds enhance, at places,

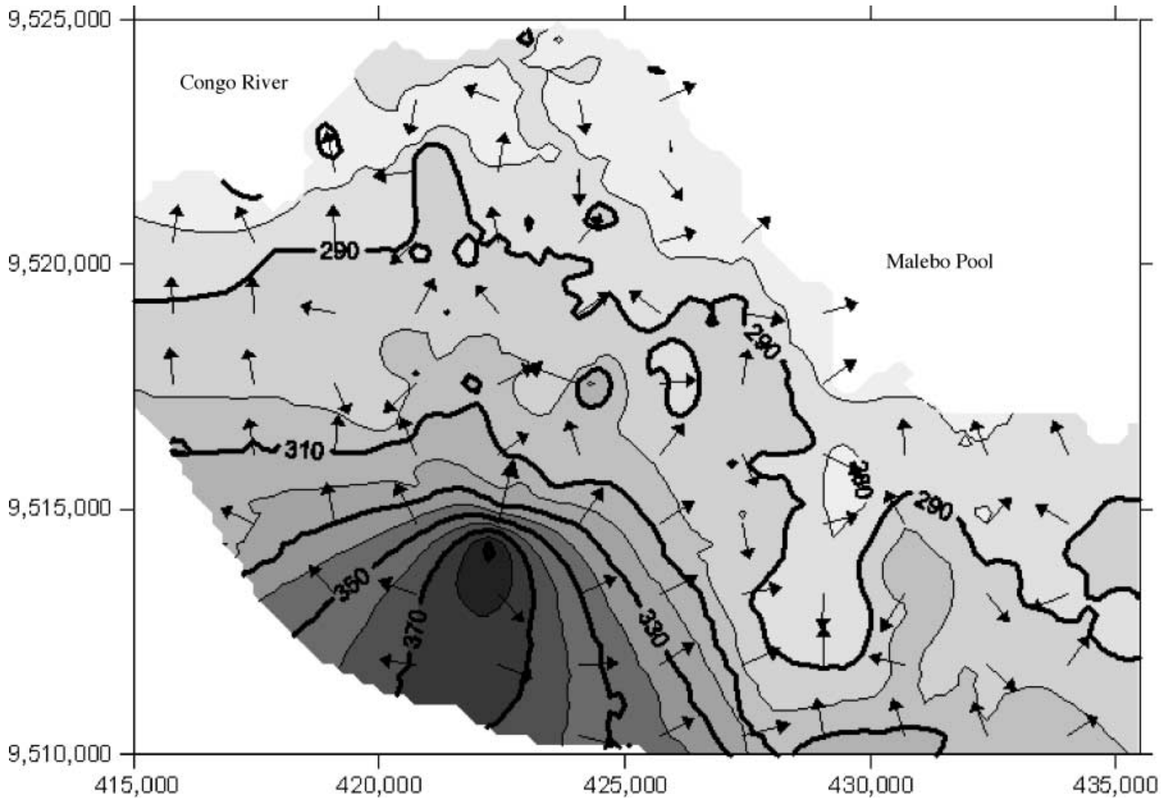


**Figure 6.** Groundwater level contour map. The static water elevation and flow directions are indicated.

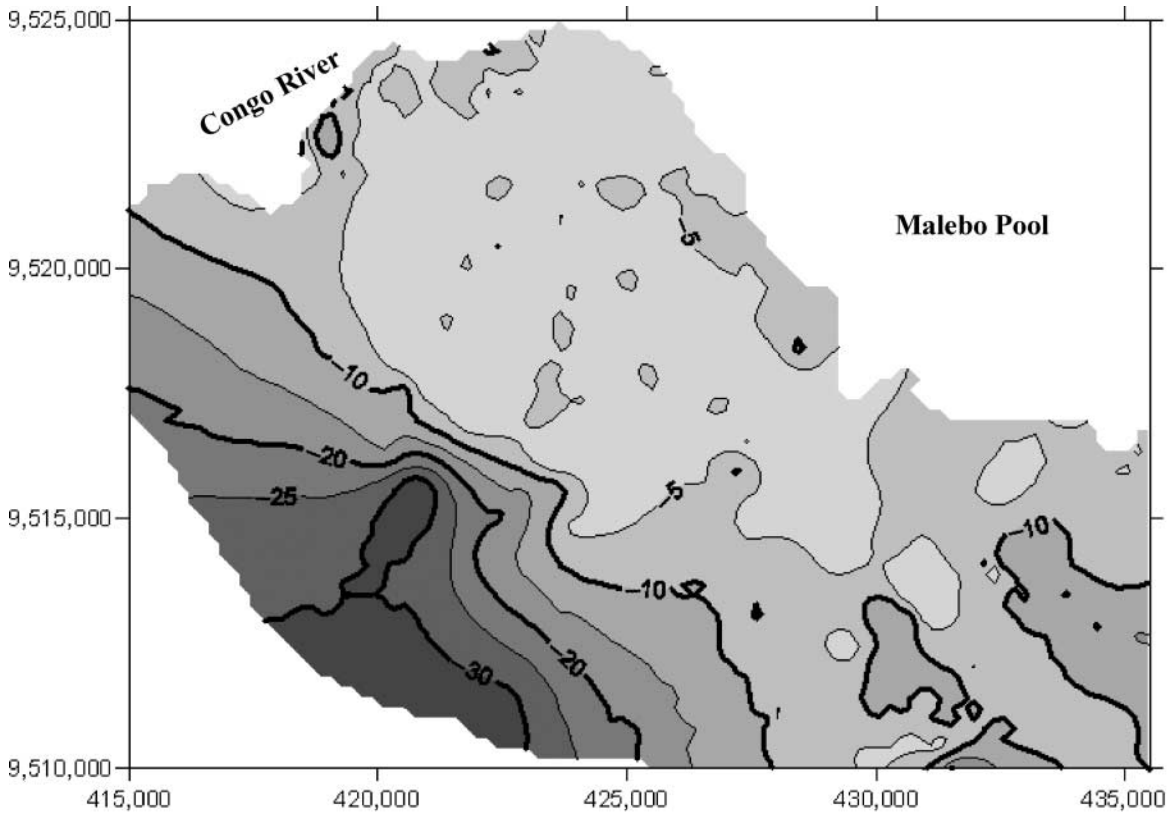


**Figure 7.** Groundwater depth contour map of Kinshasa City.

perched water-table or spatially localized aquifers. The stratigraphic relationship between the Kaoline sands and other units is not clear.

As mentioned elsewhere, the given hydrogeologic models are based on borehole data from the 1980s and earlier. More recent sets of subsurface information from Kinshasa City are not available to us. Groundwater conditions are susceptible to both climatic conditions and man-induced effects; therefore, the presented hydrogeologic model of the water-table aquifer has to be regarded as general indication for the conditions for the groundwater and its flow regime. In this regard, it is useful to recall that studies of meteorological records and climatic-geological proxies for the last 200 yr (Nicholson, 2001) showed that Africa has been affected by increased aridity particularly since the 1980s. It has also been stated that since the mid-1970s, rainfall declined in north Congo and in west Africa. Rainfall decline in north Congo is $-3.2 \pm 2.02\%$ per decade (Nyong, 2005). However, we infer that man effects on groundwater level and flow direction are not high. The immaturity of urban structures in Kinshasa City, e.g., absence of subways, large pipelines, and deep foundations of civil structures, suggests that no serious human intervention on shallow groundwater flow regime occurs. This is further enhanced by both the insignificant harvesting of the water table and the abundance of rainfall. However, groundwater recharge and surface runoff should have been modified particularly in heavily populated zones of Kinshasa (e.g., the Ville and the downtown Cité). The presence of impervious surfaces, such as buildings, paved roads, as well as any existing storm drains, affects the recharge of the water table. Human effects, however, are higher with respect to groundwater quality. We shall come to this point in another section.

## Geotechnical Aspects

No statistics or surveys about the distribution of buildings by size or classification of buildings into size categories exist. Kinshasa City, unlike many other megacities of the world, lacks significant large civil structures. To symbolize this fact, it is enough to mention that the 22-story building of the mineral marketing company SOZAKOM is a landmark in Kinshasa. The city is characterized by horizontal development with dominant light structures. A one-story, light dwelling with tin or corrugated iron roofs is the common style of dwellings as we radiate from the Ville toward the shantytowns.

This suggests that soil settling is not an imminent geotechnical problem. However, serious geotechnical problems arise in relation to sheet floods and soil erosion, topics that are covered in a separate section. However, planning and sustainable development of the city calls for the knowledge of the geotechnical parameters that govern the safety not only of current civil structures but also those of the future. Before we proceed further, note the work of Van Caillie (1977–1978) who provided the first geotechnical map for Kinshasa City.

Using data from more than 1270 boreholes, constructing important depth and thickness maps that can be used in future geotechnical and engineering activities was possible.

In this study, we recognize three major geotechnical units: (1) superficial loose sediments; (2) underlying consolidated formations, principally the Grès Tendre (as the Grès Polymorphes unit is highly reduced in the location of Kinshasa City); and finally (3) very hard Inkisi siliciclastics that form the basement of all overlaying deposits. Based on the available data, we compiled two maps: (1) thickness map (isopach) of unconsolidated deposits (Figure 8) and (2) depth (isohypse) map of the hard Inkisi siliciclastics (Figure 9). The superficial unconsolidated clayey sands vary in their geotechnical stability features according to the mixing of the two lithologic end members (clay and sand). The more clayey the component, the more stable the soil. Figure 8 is also utilizable for groundwater resource studies (see Water Resources section).

The relatively deep occurrence of the hard Inkisi substratum in many parts of Kinshasa City does not allow its incorporation as a safe foundation for large buildings. Moreover, the unit is overlaid, in some places, by a weathered topmost part that has variable thickness in different parts.

This work has no contribution on specific geotechnical parameters. These fall within the domain of site investigation studies. However, it is informative to indicate that a previous study (Van Caillie,1989–1990) provided the following geotechnical parameters of the superficial sands of Kinshasa.

- Permeability ($k$) = $4.10^{-3}$ to $1.10^{-2}$ cm/s
- High dry density = 16 kN/m$^3$
- High internal angle of repose = 10° to more than 30°
- Null cohesion = ≤5 kN/m$^2$

The level of humus content is weak to very weak.

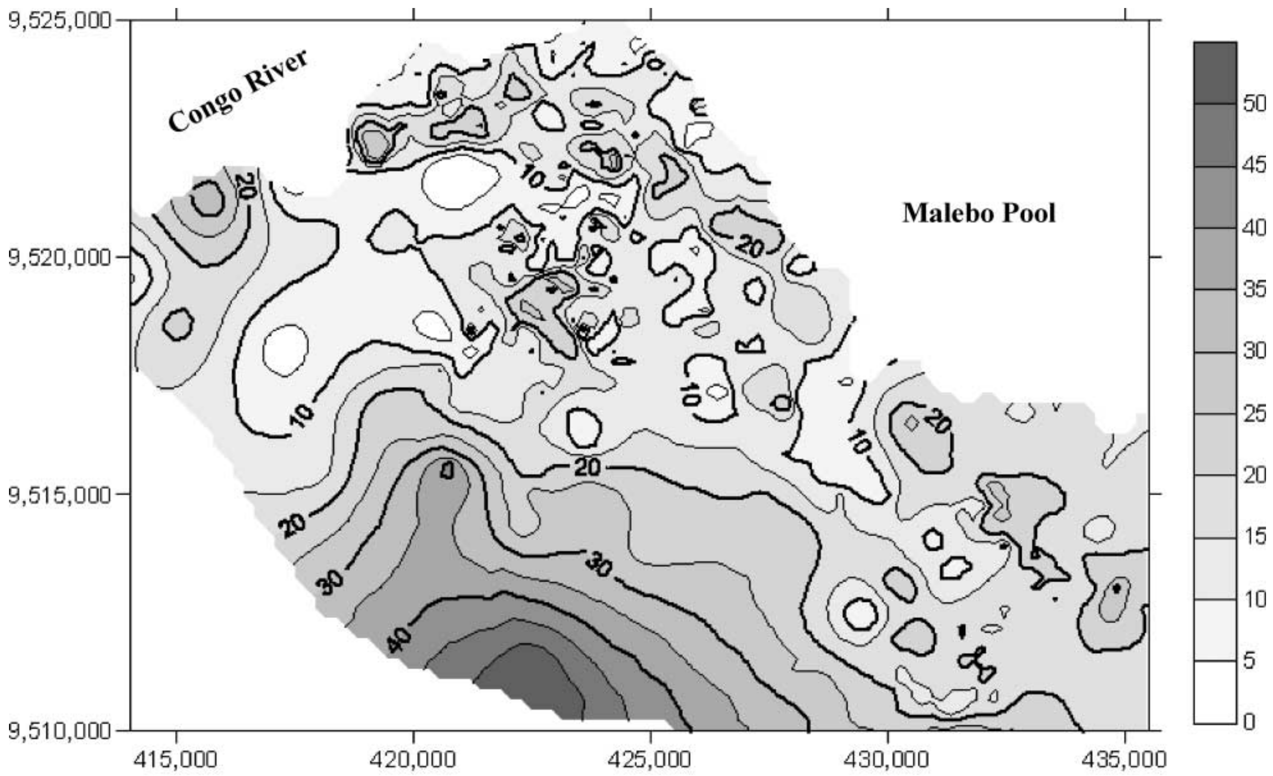


**Figure 8.** Thickness (isopach) map of the unconsolidated sediments of Kinshasa City. Limited data come from the hilly zone.

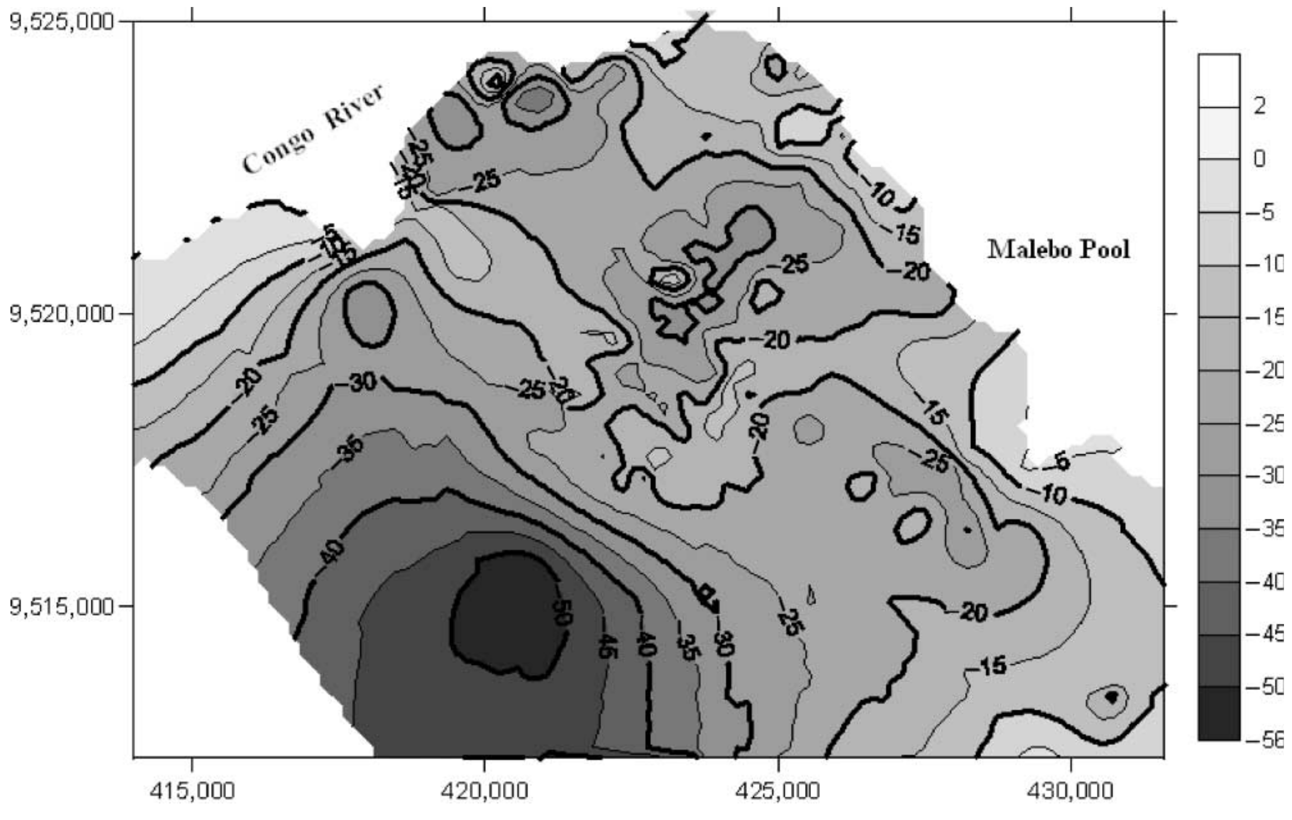


**Figure 9.** Depth (isohypse) map of the hard basement Inkisi siliciclastics. This unit is the hardest rock unit in the Kinshasa region.

## Natural Hazards

### Pollution of Water Resources

Drinking water quality is a major concern for the population of Kinshasa City. The chaotic expansion of the city, exhausted distribution network and water treatment facilities, absence of potable water, and sewage networks in many parts of the town are all potential health hazards to the population. The sources of water pollution in Kinshasa City come from human, industrial, and agricultural wastes. Corrosion and leakage of the water network pipes is another source of contamination.

Fecal pollution is hazardous because of direct evacuation of human wastes into streams. The same is also true for industrial wastes. Industries in Kinshasa are devoid mostly from treatment and recycling facilities. Their wastes, with serious toxic and pathogenic pollutants, are discharged into the Congo River (C. M. M. Nsakala, 2007, personal communication).

Also, agricultural activities contribute further to the pollution to an extent that exceeds what one expects for an urban setting. The presence of rural-urban communes in Kinshasa City, the rural nature of many of the population, and common occurrence of house gardens mean that fertilizers and insecticides may impact the quality of the water resources.

The old age of the water distribution network and the absence of rehabilitation and maintenance lead to deterioration of water supply pipes. A new preliminary study (E.A.D. Musibono et al., 2007, personal communication) brought an alarming observation that the concentration of heavy metals (cadmium, mercury, and lead) is higher in tap water (i.e., after treatment) than in the stream water (i.e., before treatment), which suggests a role of the water distribution network in raising the concentration of toxic contaminants.

As mentioned previously, the Congo River, as well as its tributary streams has effluent character. Groundwater, therefore, contributes to the quality of surface water. Polluted groundwater is not only unsafe as potable water but it also affects the quality of currently exploited surface waters. Interaction between the shallow aquifer and surface drainage system or hydrographical elements can be anticipated from Figure 10.

The water-table aquifer and other deeper unconfined aquifers are vulnerable for fecal, industrial, and agricultural pollutants. The general direction of migration of contaminants in groundwater is toward the stream drainage as can be inferred from Figures 6 and 10.

Indeed, sanitation in the city is precarious. Epidemic diseases could spread quickly among population by means of polluted waters. Cholera is known to be an endemic in Kinshasa.

Analysis of groundwater flow pattern and its relation to surface water resources is useful to evaluate the interaction between groundwater and surface water. The process we identify here is that groundwater has direct effect on surface waters.

Flow patterns of the water-table aquifer correlate well with the drainage system. Groundwater flow generally reflects the physiographic gradient. Discharge occurs to streams and to the Congo River (gaining river) but also to depressions (swamps). This picture enhances the impact of the shallow water aquifer on the quality of the surface water resources, which is important to understand because the unconfined aquifer system of the city is vulnerable to pollution form human, industrial, and agricultural wastes.

In a recent study, we found that levels of heavy metals in the city drinking waters are higher during the wet or rainy season (E.A.D. Musibono et al., 2007, personal communication). We expect the same for fecal pollutants (fecal coliforms, *E. coli*, and other intestinal bacteria) because flooding in the city is accompanied by overflow of latrines.

### Mass Wasting and Accelerated Erosion

Streams downcutting and dissection of the landscape are observable natural phenomena in the whole region. They are attributed to a regional tectonic uplift, leading to the lowering of the regional base level of erosion (see, e.g., Cahen, 1954; De Ploey, 1965; Lepersonne, 1974).

In Kinshasa, large amounts of soil are removed from the landscape and become part of streams and river loads. Field measurements (Van Caillie, 1989–1990) indicate that the mean surface lowering, as a result of erosion, is equal to –0.74 cm (–0.29 in.)/yr.

Stream landslides and backward erosion are man-induced hazards that accompany vertical incision of valleys and watercourses. Erosion at heads of valleys produces wide semicircular erosional cirques that attain in some parts great dimensions of more than 200-m (656-ft) depth and few square kilometer surface area (see e.g., Van Caille, 1983; Salomon, 1998). The slopes of these cirques in their turn become eroded by new ravines, and their heads advance steadily.

The rate of soil erosion depends on both erosivity (related to kinetic energy of rainfall and runoff) and

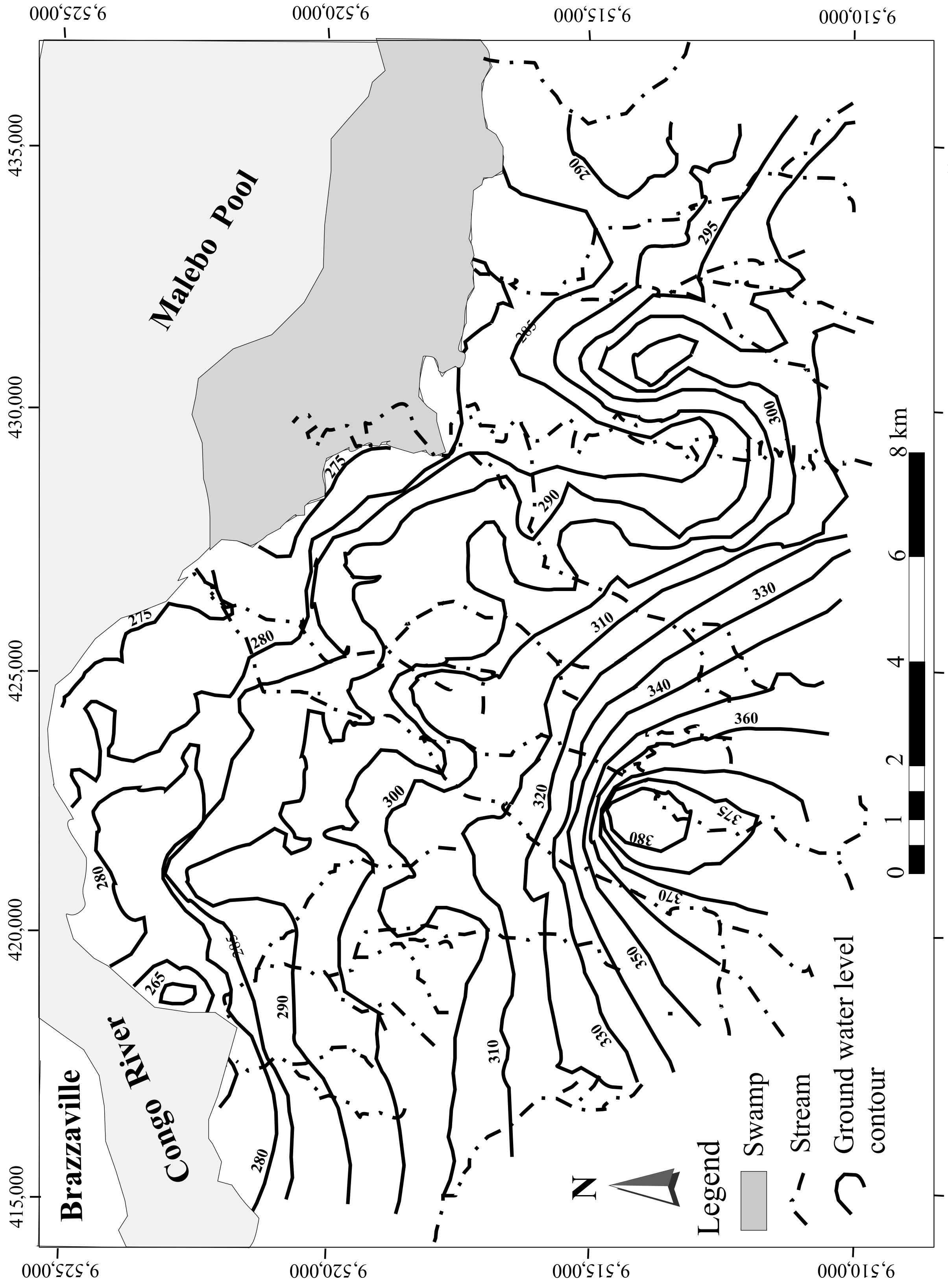


**Figure 10.** Overlay of the Kinshasa City drainage system on groundwater level contours. Correlation exists between these two features.

erodibility (related to soil texture, slope, vegetation cover, and human effects). Occurrence of prolonged heavy showers, net rain excess, and torrential floods means high erosivity. Dominance of unconsolidated fine sands in the landscape of Kinshasa City is of particular significance for the observed high erodibility. The very low content of organic matter (see Geotechnical Aspects section) leads to low aggregate stability. The hilly topography introduces the function of slopes (both in terms of steepness and length) in raising the kinetic energy of running water and shear stress of overland flow. This raises the erodibility of the terrain. The surface runoff becomes effectively erosive when the slope gradient exceeds 15°. This is important to consider when we recollect that a previous study found that 20 to 39% of slopes have gradients between 12.5 and 20% and 12 to 19% of slopes have gradient exceeding 20% (Van Caillie, 1989–1990). Therefore, large areas in the hill zone are prone to the risk of erosion. Vegetation has the role of fixing the soil and dispersion of surface runoff. Clearance of slopes from their natural vegetation as a result of spatial expansion of the Kinshasa slums, and to a lesser extent by fires, increases erodibility. Furthermore, human activity affects landscape erosion in other ways. The introduction of impervious surfaces (buildings, pavements, etc.) and the absence of storm drains and drainage system lower the dispersion of runoff and concentrate it as runoff along unpaved roads transforming these into gullies and ravines. The rate of spread of erosion is enormous. Recently, the Digital Congo.net network reported that a small hole in Laloux in 2000 has become a great ravine in 2006, which causes the destruction of many houses after each torrential rain and currently threatens the main western artery (Route Matadi). Therefore, it is not a joke when we read in the Congolese mass media that inhabited surface areas of certain communes of Kinshasa should be recalculated after each rainy season! Also, the extreme idea that the city would be divided by ditches is a reality. From an environmental assessment point of view, we may assign Kinshasa as a model of an urban morphogenetic crisis area. The risk of erosion is well heralded on both scientific and mass media levels, but measures to implement solutions remain inadequate. Even the joint endeavors between the Congolese government (Ministry of Public Works) and the United Nations (United Nations Development Program [UNDP] and United Nations Center for Human Settlements [UNCHS], Project ZAI/97/016, 2000; and the HSP Program, 2002) remained mostly ineffective and were no match to the scale of the problem.

### Floods

Rainfall in the Kinshasa region exceeds infiltration capacity. Urban surfaces decrease farther downward percolation of rainwater. Therefore, abundant surface runoff during the wet season is observed particularly during November. Rainfall is mostly in the form of torrential downpours. This feature coupled to other catalysts makes floods a serious concern to the city.

Floods in the Kinshasa City area occur along three geomorphologic elements: the Congo River, the tributary streams, and sloping planes. The first two are affected by more than one watershed that has regional scale. The third is governed mainly by local conditions and individual subwatersheds.

The Congo River is characterized by a regular flow, but at times, it becomes a wrathful river. The floods of 1908, 1962, 1979, 1997, and 1999 are witnesses of such energetic states of the river. Until 1940, the observed maximum rise of level of the river was 5.6 m (18.3 ft) (Lepersonne, 1937). The unusual flood of 1961 had a high-water mark of 5.20 m (17.06 ft), whereas the more severe flood of 1999, the worst flooding of Kinshasa for decades, brought the high-water mark to 5.44 m (17.85 ft). Taking the average level of the Congo River as 298 m (978 ft) a.s.l., these figures mean that floodwater could approach the contour value of 304 m (997 ft). This means in turn that many low-laying parts of Kinshasa that have been squatted in recent decades are at risk, including deeper inland tongues.

The events of the December 1999 flood gave an idea about the scale of the risk that Kinshasa faces with respect to floods of the Congo River. Thousands of people were evacuated and potable water supplies were reduced to cover only 50% of the population of the capital.

However, the more frequent and more troubling hazard to population and urban structures comes from sheet floods and flooding of tributary streams.

In October 2007, flash floods struck Kinshasa after a record rainfall (222 mm/m$^2$) with the result that many people lost their lives, hundreds of houses were destroyed, and thousands became homeless. In this event, streams overflowed their banks and raised to the level of bridges, deep erosion and landslides occurred, power lines were knocked down, and many bridges gave way. These have lead to the isolation of some communes and complicated rescue operations. Inundation of dwellings brought with it also health concerns and prospects of disease outbreaks as a result of the overflowing of individual septic tanks and latrines (with ensuing ebbing of excreta).

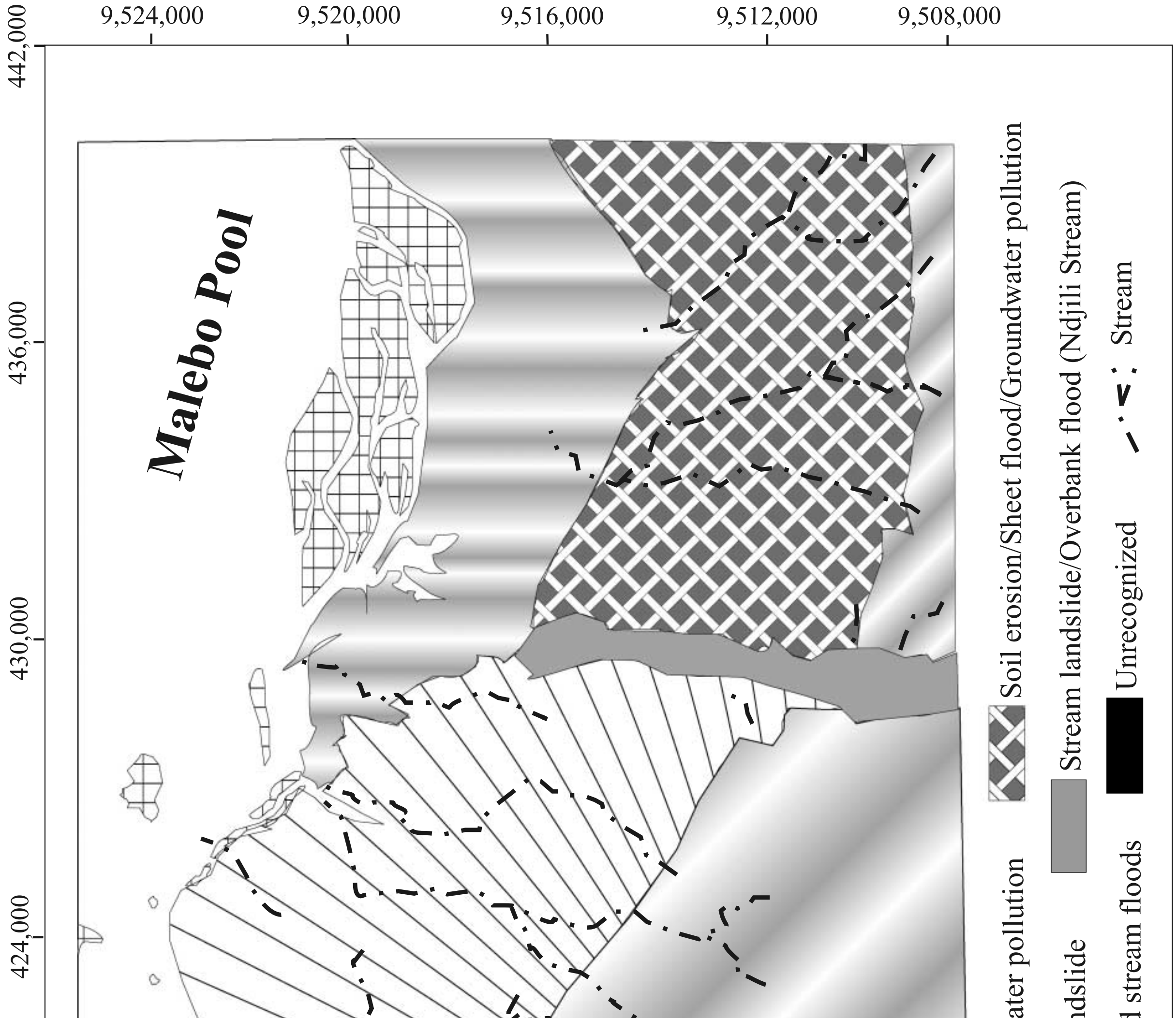


**Figure 11.** Hazard-prone areas, Kinshasa City. Five hazard types, and their combination, are recognized.

Examination of documents and statistics of Kinshasa City floods indicates that 12 communes are most prone to flood risks. These are Kisenso, Limete, Matete, Mont Ngafulu, Ngaliema, Kalamu, Kintambo, Masina, Selembao, Lemba, Bandalungwa, and Kimbanseke. It appears, therefore, that 52% of the Kinshasa area and 70% of its population are at risk from floods. Hazard-prone areas are tentatively portrayed in Figure 11. We emphasize that this is not a hazard map per se. Recognition of the type of hazard is based on ground truthing, surface monitoring records, and subsurface database.

## CONCLUDING REMARKS AND RECOMMENDATIONS

Geoenvironmental conditions and urban space in Kinshasa suffer from catastrophic threats.

Impaired water quality, soil erosion susceptibility, and floods combined with chaotic urban expansion left most of the city exposed to man-induced natural hazards, water shortage, lack of electricity, low housing quality, absence of paved roads, and a multitude of socio-spatial problems and health risks. Sustained pressure is exerted on the geoenvironment and georesources. This causes tremendous or even, at certain instances, irreversible geoenvironmental damages.

This Kinshasa City case study does not target planning for good urban occupation or management of the direction and rate of urbanization but instead tries to give information on the difficult geospatial situation and the interaction between the anthropogenic and the geologic environments.

More challenging is that the current sociopolitical and socioeconomical conditions in the Democratic Republic of Congo provide little room for implementation of remedy plans, conservation strategies, and urban policies. In the past, during the 1970s and early 1980s, serious urban plans and efforts had been made, but they have never been implemented. What is also pressing is that geoenvironmental conditions could worsen if the issue of global warming is taken into consideration. As has already been suggested, Africa is the most vulnerable region for the impacts of global warming (e.g., Houghton et al., 2001).

Even with these bleak prospects, this work enlightens planners, engineers, and decision makers about the eminent geoenvironmental hazards and provides the foundations for future programs targeting urban development of Kinshasa City. The presented geological information in map format is particularly useful for various geoengineering objectives.

Beside these, certain issues can be highlighted and provisional recommendations made.

### Potable Water Issue

In the case of the current use of surface waters, installation of additional treatment and distribution plants is needed besides upgrading existing facilities. The availability of tremendous amount of surface waters in Kinshasa means that efforts and plans to alleviate drinking water conditions should rely mainly on the Congo River as a source for the city waters. However, upgrading pumping and purification facilities is only one face of the coin. The other, and the most laborious one, is the establishment of a water distribution network to cover the various communes of the city. This means revolutionizing the financial and technical status of REGIDESO, the organ responsible for potable water distribution. This is not expected to occur before basic advancements on the level of governance and administration, which have nationwide dimension, have been achieved.

Concerning groundwater, its exploitation might be considered as an ephemeral alternative, but it assumes urgent consideration in the current sociopolitical and economical conditions of the Democratic Republic of Congo that do not permit near-future progress on the level of exploitation and distribution of surface waters. Exploitation of groundwater resources is easy and cheap with less investment. Tapping groundwater is within the domain of individual activity. This suggests that, in light of what we know of the absence of a potable water distribution network in many districts and communes of Kinshasa, initiating a hand-pump project could prove a practical solution but not without the constraints on the sustainability of such project due to both institutional and community factors. Shallow boreholes can be drilled in various localities and equipped with modern hand pumps to provide local but effective services to the population. An alternative technology is to make well-constructed deep hand-dug wells equipped with bucket and windlass or bucket pump. In rural-urban communes, the choice of a family approach, i.e., family-based shallow well approach, could be beneficial. In this regard, it is always important to consult inhabitants on the choice of technology to be used. Technology of choice should have low cost, and be appropriate to the local socioeconomical conditions with affordable operation and maintenance demands that are manageable by the local community. There remains the challenge of pollution of the groundwater. Water quality could be alleviated by careful well design and protection.

### Degradation of Landscape, Erosion, and Floods

The physical factors and anthropogenic catalysts of landscape degradation and soil erosion in Kinshasa were given. Suitable soil conservation strategies are needed. Conservation measures may include delineation of residential areas lying on slopes exceeding 15° that are more susceptible for erosion, fixation of erosion-prone slopes by vegetation, and construction of storm drains and an effective drainage system. Maintenance and rehabilitation should be part of a continuous program. Specific detailed geotechnical and geoengineering studies are needed to provide effective and economic designs and solutions.

### Pollution

Treatment plants for wastewater, recycling facilities, and availability of sewage network represent the desired solution to the water pollution problem in Kinshasa City. The current socioeconomical and political conditions in the Democratic Republic of Congo do not permit optimism and we have no illusions in this regard. The social character of the Kinshasa inhabitants and their low income allow but little room for the role of population contribution and public awareness to mitigate the effects of degradation of the landscape and its resources. The only realistic measure, in current conditions, may be the use of governmental supervisory bodies to oblige industries to install treatment facilities and pollution control units for their wastes.

This article illustrates the role of geologic characteristics of the terrain in urban environmental decline. This role has universal nature and is common to all other Third World megalopolises. Urban geological mapping and environmental geological work can recognize and delineate potential urban natural risks that threaten community safety. In light of what is observed of the insignificant incorporation or even the absence of geologic studies in the procedures of many national urban planning departments, we recommend geological investigation to become a working component of urban sustainability programs in developing countries.

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