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Estimation Of Groundwater Recharge In Kinshasa Capital Region (D.R. Congo) Fusing GIS And Empirical Based Schemes

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Abstract
No more than a year, the Kinshasa Capital has experienced heavy flooding causing much damage; these floods which were strong in the flat part of the City, part located in the North and North West of the City were due to the rapid and chaotic urbanization in which certain houses are built on main sewers which have the role of the drainage of all the waters towards the Congo river, thus preventing them from being unclogged once clogged on the one hand, and on the other hand due to the presence of impermeable surfaces (buildings, roads, almost entirely paved plots etc.) without forgetting the presence of sands - clayey located in this part of the city. All these situations affect the recharge of aquifers; this is why the main objective of this study was to estimate the groundwater recharge by comparing the GIS Method to that of the Empirical Method in an area of 2,187.36 km^2. To achieve this main objective, one the one hand, the GIS tool was used to compile spatial analysis by producing maps such as: Rainfall Distribution Map, DEM, Topographic Map and Contour Map, Soil Map, Slope Map, Drainage Density Map, LU / LC Map and Runoff Map. The compilation of all these Maps allowed us to highlight the recharge map in which we could locate the high and low recharge zones. And on the other hand, the U.P. Irrigation Research Institute, Roorkee allowed us to bring out the annual groundwater recharge using their empirical formula. The results of this study show that according to the U.P. Irrigation Research Institute, Roorkee, the annual recharge of groundwater in our study area using their empirical formula was estimated at 236.21 mm /year, for a period of 2000 to 2013 respectively which is consistent with Arcgis 10.5's calculated recharge value of 238.801mm/year. With the Average Rainfall of 1540.04 mm/year, the Evapotranspiration of 1151.57mm/year, the maximum runoff of 409.085 mm/year, the Effective Rainfall Pe was estimated at 388.47mm/year and the Recharge Coefficient was estimated at 60.8%. Noted that this groundwater recharge is strong in Southwest and less in paved areas and clay-sand soil type to East.
Keywords: *Gis Method; Empirical Method, Groundwater Recharge; Land use/Land cover Impact.*

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I. Introduction

The estimation groundwater recharge is a very important parameter for the assessment and management of groundwater resources (Islam *et al.*, 2016). A thorough estimation of groundwater recharge is a prerequisite for efficient groundwater resources management.

Groundwater is contained in the subsoil where it can move and store under the influence of various factors that may be hydrogeological, hydrological and climatic (Kumar, 2013). Recharge is one of the factors that influences and controls the status and fluctuations of groundwater, which is why it deserves to be evaluated in detail (Saghravani et al., 2013).

Worth mentioning that the determination of the recharge rate of the aquifer is neither simple nor easy, especially in the zones characterized by a temporal variation of precipitations and by a spatial variation of the characteristics of soil, topography, land use and soil cover use (Kuruppath et al., 2018) because a set of factors namely precipitation, soil texture, slope, drainage density, land use, land cover, topography, etc., influence small and large scale groundwater recharge (Sumioka and Bauer, 2003). Hence, it is important and imperative to estimate recharge in order to properly manage and protect valuable groundwater resources using modeling tools or empirical formulas. That's why the estimation groundwater recharge is a very important parameter for the assessment and management of groundwater resources (Islam et al., 2016), especially for areas in which groundwater is vital for the local water supply (Yun et al., 2011), and also it is important to understand how land use/ land cover impacts groundwater recharge, especially for regions that are undergoing rapid and chaotic urbanization (Yun et al., 2011).

Alley (2014) depicts a groundwater system as a structure containing the subsurface water, the rocks bearing water, flow boundaries conditions as well as water input such as recharge (sources) and output such as springs, inter aquifer flow, or wells (sinks).

According to Scanlon et al. (2002), the quantification of groundwater depends on recharge or effective infiltration defined as water that can percolate vertically downward from the base of the soil zone up to the water table. Furthermore, Bekesi and Mcconchie (2018) pointed out that the estimation of groundwater recharge is a key element in determining the sustainable yield of groundwater resources, which can lead according to Rawat et al., (2012) to a good groundwater resource management policy on a regional or large scale for an entire aquifer and also note that the groundwater regime depends to a large extent on both recharge and its coefficient. These two parameters can be determined by means of empirical methods depending on the climate of the study area.

In the Kinshasa Capital Region, studies solely dedicated to groundwater estimation are practically inexistent. Owing to difficulties in conducting experimental methods for the estimation of groundwater recharge, that’s why this study is based on the comparison between GIS Method and Empirical Method in estimation of groundwater recharge under land use/ land cover impact in Kinshasa Capital (D.R. Congo).

II. Materials And Methods

The simple water balance model using the GIS environment was used to quantify the spatial distribution of groundwater recharge based on the components of the Kinshasa Region water balance. This regional model had taken into account chaotic urbanization due to exponential population growth, which changed land use / land cover with a significant reduction in areas of unoccupied bare land (Figures 10 and 11). This reduction in bare land has significant impacts on groundwater recharge in the study area. The GIS environment was used to compile spatial analysis by producing maps such as: Rainfall Distribution Map, DEM, Topographic Map and Contour Map, Soil Map, Slope Map, Drainage Density Map, LU / LC Map and Runoff Map. The compilation of all these Maps allowed us to highlight the Recharge Map in which we could locate the high and low recharge zones. The GIS method was finally confronted with an empirical method of the U.P. Irrigation Research Institute, Roorkee which allowed us to make the comparison between the two methods as shown by the conceptual framework presented in figure 2.

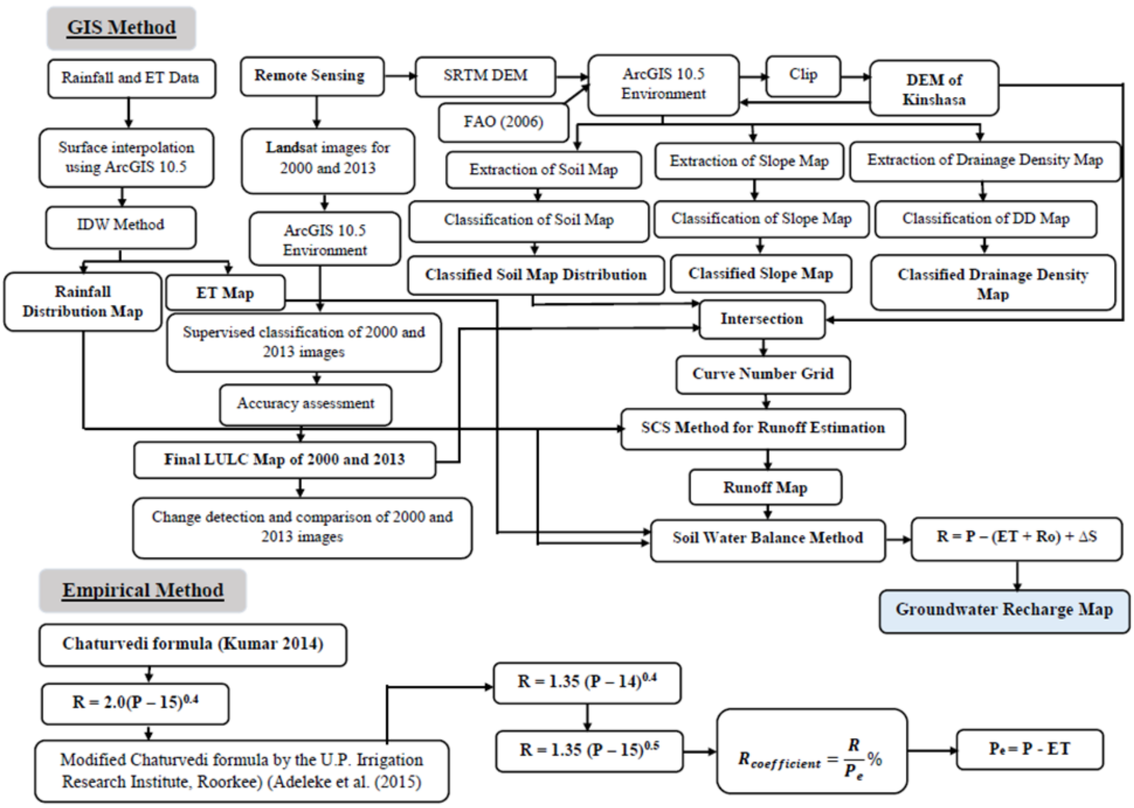


Figure 2: Conceptual Framework

GIS Method (Curve Number Method)
Monthly Rainfall Analysis

All rainfall data used in this study comes from rain gauges of the RD Congo's Meteorological Services better known as MetelSat scattered in Kinshasa during the period ranging from 1961 to 2018 which obviously includes our period of study going from 1984 to December 2013 (30 years). Of the three stations covered by MetelSat, only two were used for the analysis due to the availability of a complete series of rainfall data. The Thiessen polygon method was used for two gauging stations namely Binza and N'djili using ArcGis 10.5 to estimate the spatial distribution of rainfall as well as to uncover the rainfall gauging stations influencing the watershed.

Taking into account the spatial distribution of the meteorological stations in the study area, the inverse distance weighting (IDW) method was used to interpolate precipitation in order to obtain the precipitation distribution map. This interpolation method combines the concepts of proximity to follow the Thiessen polygons with a gradual change in the trend area (Magesh et al., 2012). Therefore, ArcGIS 10.5 was used to interpolate the precipitation distribution of the Binza and N'djili stations in the watershed. Table 1 below shows the location of each rainfall gauging station in the study area for the period from 1984 to 2013.

Table 1: Rainfall Gauging Stations Distribution in the Study Area with Measured Data

Station ID	Station Name	Latitude (UTM)	Longitude (UTM)	Elevation (m)	Mean Annual Rainfall (mm)
64210	**N'Djili***	15.43333	-4.38333	311	1519.81
64220	**Binza***	15.36667	-4.36667	445	1560.863
64211	Ndolo	15.3	-4.31667	279	Incomplete record

**Rainfall Stations used*

Digital Elevation Model (DEM)

A 30 by 30 SRTM Digital Elevation Model of Kinshasa was downloaded and clipped using ArcGIS 10.5 in order to show hydrological parameters such as flow accumulation, flow direction and streams network.

Topographical and Contour Map

ArcGIS 10.5 allowed us to generate a topographic map of the study area from the 254 boreholes location data. ArcGIS 10.5 helped in the design of a contour map from the DEM of the study area because as pointed out by Nkeki and Asikhia (2014), before the widespread use of DEM-based data to represent land irregularities, contour lines and spot heights were commonly used as an effective method for mapping topographical characteristics. Passing through contour (Spatial Analyst tools) and choosing 100m as the distance between contours and leave the default of 0 the base start contouring, we created our contour map.

Soil Map

The soil map of the study area was obtained from FAO (2006). ArcGIS 10.5 was used for clipping and projecting the study area in UTM zone 33 South for further analysis. The soil map shapefile obtained from FAO (2006) categorizes soil as acrisols, arenosols, ferrasols, and water bodies and ArcGIS 10.5 was used to classify the soil texture. Table 2 below shows the soil map classification of the study area.

Table 2: Soil Map Classification base on FAO (2006).

Soil Name	Soil Texture	Area	Percent
Ferrasols	clay (light)	0.852307	0.038965
Water Bodies	Water	55.715898	2.547172
Acrisols	Sand	823.847113	37.663939
Arenosols	Sand Clay	1306.947784	59.749924

Slope Intensity Map

The DEM of Kinshasa city was used to generate a slope intensity map expressed in percentages through the ArcGIS 10.5 environment. The generated slope map was classified into 7 classes (Table 3) according to FAO (2006).

Table 3: Slope Classification of Kinshasa based on FAO (2006).

Class	Description	%
1	Flat	0 - 2
2	Gently sloping	2 - 5
3	Sloping	5 - 8

4	Strongly sloping	8 - 16
5	Moderately steep	16 - 30
6	Steep	30 - 45
7	Very steep	> 45

Drainage Density Map

From the SRTM DEM of Kinshasa city, all drainage related properties were calculated using the embedded hydrological tools in Arc GIS 10.5. In fact, the density line tool was used to generate the drainage density of Kinshasa city.

Land Use/ Land Cover Map

To reach our assigned goals, we resolved to generate two land cover maps of the 2000 and 2013 cover to see the growth or decrease of parameters such as vegetation, urban planning, agriculture, etc., in order to estimate the land use/ land cover impact on groundwater recharge. Land cover maps of the 2000 and 2013 were obtained through Landscapes 2000 and 2013. ArcGIS 10.5 was used to extract the study area in the city of Kinshasa from Landsat's image and projected it in the UTM 33 South zone for further analysis. ArcGIS has also been used for further classification.

Runoff Map

There are number of methods available for rainfall runoff modeling such as hydrologic models, empirical equations and data driven techniques to correlate rainfall and runoff (Zakwan, 2016). Soil Conservation Services and Curve Number (SCS– CN) technique is one of the primogenital and simplest method for rainfall runoff modelling and it may also be used to determine the amount of rainfall that will infiltrate into the soil (Zakwan, 2016). To estimate runoff potential, rainfall distribution, digital elevation model (DEM), soil texture and Land Use/Land Cover were considered and all these parameters were processed in ArcGIS 10.5 and Soil Conservation Services Curve Number (SCS– CN) method was used to compute runoff volume. The (SCS– CN) approach involves the use of simple empirical formula, tables and curves. The empirical equations require the rainfall and watershed coefficient as inputs. The watershed coefficient called as curve number (CN) is an index that represents the combination of hydrologic soil group (HSG) and land use and land treatment classes (Zakwan and Zeenat, 2018).

Groundwater Recharge Map

Estimating the groundwater recharge is one of the most difficult measures regarding groundwater resources. There is more than one method that estimate groundwater recharge, yet a large amount of errors is normally subordinate. However, calculating groundwater recharge can be estimated on a wide set of methods in order to give the closest estimation of recharge (Qablawi, 2016).

Depending to literature, they are several methods of estimating groundwater recharge such as: Soil Water Balance method, Chaturvedi formula, Seasonal Recession method (Meyboom Method), Well Level Data method etc. But in this work, the Soil Water Balance method was used because this approach has an advantage since it estimates direct groundwater recharge using available climate data (Melo et al., 2015). The parameters of the soil water balance method are precipitation, evapotranspiration, runoff and soil water storage.

The equation bellow describe the Soil Water Balance Method (Kumar, 1997):

$$R = P - (ET + R_O) + \Delta S$$

Where:
R = Groundwater Recharge (mm/year)
P = Precipitation (mm/year)
ET = Actual Evapotranspiration (mm/year)
Ro = Runoff (mm/year)
ΔS= Soil Water Storage

According to Li et al., (2007) over a long period of time (i.e. 10 years), it is reasonable to assume ΔS is zero and in our case we have 14 years, which mean that the ΔS is zero.

Empirical Method
Recharge Estimation

Different empirical formulas, namely Chaturvedi, UP Irrigation Research Institute, Amritsar, Kumar Seethapathi Krishna, and Rao, have been proposed and used to estimate recharge in different countries.

Kumar (2014a) reports the following empirical relationship credited to Chaturvedi (1936) for the assessment of the recharge as a dependent variable exponentially linked to annual precipitation after a study focusing on the water level fluctuations and rainfall data in the Indian region of Ganga-Yamuna Doab :

$$R = 2.0\ (P - 15)^{0.4}$$

Whereby,
R denotes net recharge due to annual precipitation (inch);
P is yearly precipitation (inch).

Scientists at the Irrigation Research Institute, Roorkee (formerly the U.P. Irrigation Research Institute, Roorkee) modified the Chaturvedi formula as reported by Adeleke et al. (2015):

$$R = 1.35\ (P - 14)^{0.5}$$

Where,
R is a net recharge due to annual precipitation (inch);
P is yearly precipitation (inch).

As pointed out by Kumar (2014a) and Adeleke et al. (2015), **The Chaturvedi Formula is used worldwide** for preliminary evaluation of groundwater recharge from annual precipitation data. Worth mentioning that recharge due to precipitation is zero below a lower limit of rainfall. The amount of precipitation recharged begins at zero correspondings to P = 14 inches, increases to 18% at P = 28 inches and decreases again. In the modified Chatuvedi formula, the lower limit of precipitation allows an interpretation in hydrological loss terms such as runoff, soil moisture deficit, interception and evapotranspiration. A generalization of the application of the Modified Chatuverdi Formula to all floodplains is not possible because the aforementioned controlling factors of the equation are site-specific. Therefore, the Chatuvedi Formula must be checked or appropriately modified to the study area because it was originally developped for site specific hydrogeological conditions of the Indian Ganga-Yamuna Doab area.

Among the many equations for estimating recharge, the below equations was used in this study.

$$R = 1.35\ (P - 15)^{0.5}$$

With:
R = Net recharge from precipitation during the year (inch);
P = yearly precipitation (inch).

Estimation of Recharge Coefficients

There are several methods in the literature for the estimation of groundwater recharge coefficient commonly defined as the ratio of the actual recharge to the effective rainfall, usually expressed in percentage (Misstear et al. 2009 cited by Allocca et al., (2014)). According to Adeleke et al. (2015), the value of the recharge coefficient can be expressed as :

$$R_{coefficient} = \frac{R}{P_e}\%$$

Where R is the recharge and P_e is the effective rainfall.

Estimation of Effective Rainfall

Saghravani et al. (2013) suggest the following equation to calculate the effective rainfall.

$$P_e = P - ET$$

With P standing for precipitation (mm/month). As aforementioned, P_e as the effective precipitation (mm/month) is always larger than or equal to zero, and ET denotes the evapotranspiration.

The Study area

The city of Kinshasa is located in the west of the Democratic Republic of Congo between 3.9˚ and 5.1˚ South latitude and between 15.2˚ and 16.6˚ East longitude. Its area is about 9965 km^2 (0.42% of that of the whole country). Kinshasa is the main administrative, cultural and economic center of the country and one of the largest cities in sub-Saharan Africa. Its geographical limits are: the Greater Province of Bandundu in the Northeast and East, the Central Kongo Province to the South and Southwest, and the Congo River with its circular Pool Malebo, a natural border with the Republic of Congo (Brazzaville) to the West and North-West (Figure 1). Water level at the pool Malebo is about 298 m above sea level whereas at the mainland of Kinshasa, the altitude from the plain in the North to the highlands of the South spans between 300 and 350 m.

The Congolese administrative province of Kinshasa is made of a total of 24 municipalities occupying 9965km² with 22 quasi-urbanized covering a total area of 590km² of the land representing 6% whereas the two urban-rural municipalities cover approximately 9375 km² or 94% of the overall area.

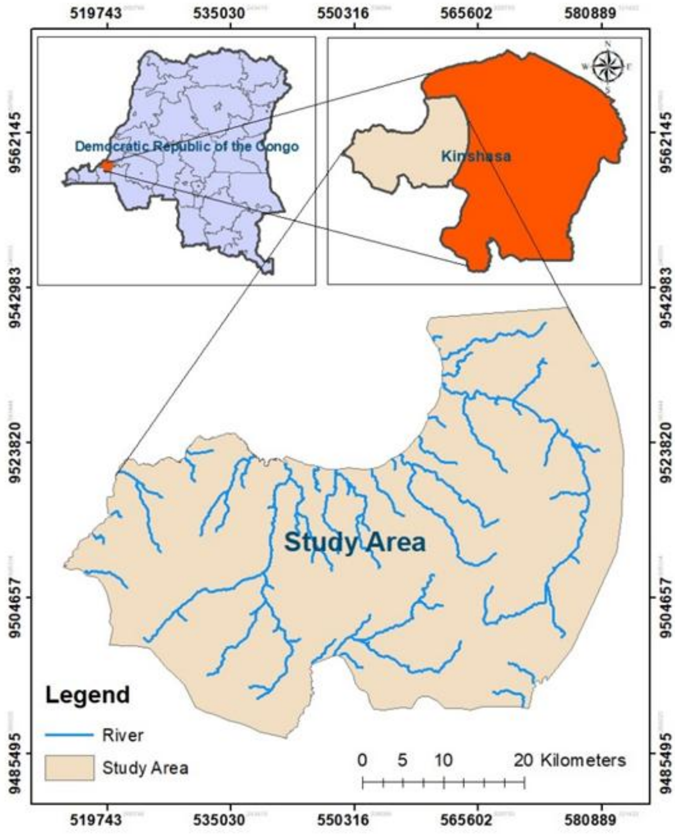


Figure 1: Location of the Study Area

The climate of the Capital Region of Kinshasa is of the type Aw4 (tropical soudanian) or soudano-guinean according to Köppen climate classification system (Devroey and Vanderlinden, 1951). It has two major marked seasons namely a wet and warmer season (October to May) with an average temperatures of 25.6°C and a dry and relatively cooler season (June to September) with an average temperature of 22.8°C. The average relative humidity spans between 71% and about 84% whereas the annual rainfall ranges between 1222mm and about 1863mm. Heavy torrential rains occur in November immediately after the dry season as well as in March and April. In Kinshasa, the land is mainly covered with grass, bush-savanna and oily treelike vegetation. It is also worth mentioning the occurrence of gallery-scanty forests along streams (Lateef et al. 2010).

The bedrock is the made of the fractures-free and slightly towards northeast-dipping Inkisi sandstone underlying much younger continental sediments of fluvial, fluviodeltaic, fluviolacustrine, lacustrine, and eolian origin (Lateef et al. 2010). The lithostratigraphy of Kinshasa City is given in Figure 2 below showing the synthesis of geological formations divided into two systems of terrains, their respective thickness, and geological age.

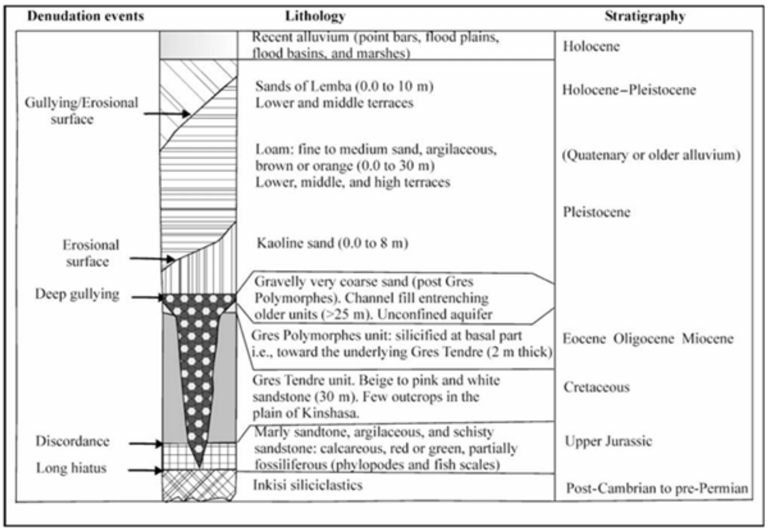


Figure 2: The lithostratigraphy of Kinshasa by (Lateef et al. 2010)

III. Results And Discussion

Monthly Rainfall Analysis

The interpretation of the spatial distribution of precipitation using the Thiessen polygon method reveals that the western part of the study area receives more precipitation than the eastern part. The eastern part is, moreover, more populated than the western part and is characterized by chaotic urbanization made of slums. The rainfall of our study area varies from 1519.81 mm (for N'djili) to 1560.86 mm (for Binza) with an average of 1540.04mm observed by a moderation of precipitation in the areas located in the center of two distribution stations. Figure 3 below shows the spatial rainfall distribution of the study area.

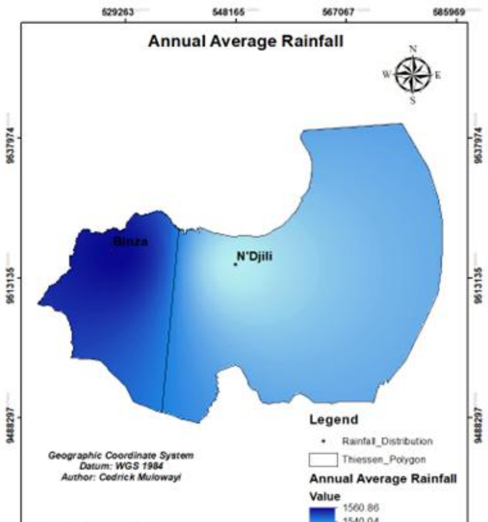


Figure 3: Annual average rainfall distribution.

Digital Elevation Model (DEM)

This DEM of the Kinshasa city (Fig. 4) shows the highest altitude which is about 732m located in the North East as well as the lowest altitude which is 223m located to the North towards the Congo River. The DEM also allows the calculation and distribution of the slopes in the study area.

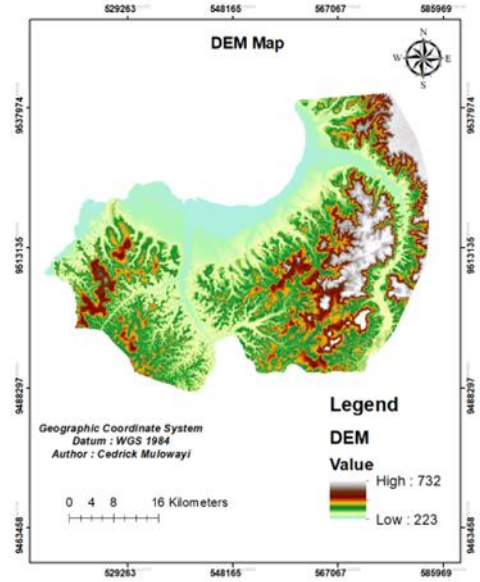


Figure 4: Digital elevation map of Kinshasa City

Topographical and Contour Map

This map helps in locating hydrological parameters such as stream network, flow accumulation, and flow direction. We can locate in this map the highest altitude which is about 673.37m located in the North-East towards Minkao followed by an altitude of about 590m located in the southwest towards Mount Ngafula as well as the lowest altitude which is 235.765m located to the North towards the Congo River. The topographic map also allowed us to calculate the slope and contours of the study area.

Topographic maps systematically describe the spatial relationship between physical features, such as contours, hydrographic symbols, and cultural features, such as roads and administrative boundaries. In addition to these hydrological parameters, this topographic map has also allowed us to understand the shape of basement structures that govern groundwater because, geologically speaking, surface modeling is often a reflection of what is deep down. Figure 5 below shows the topographic map of Kinshasa.

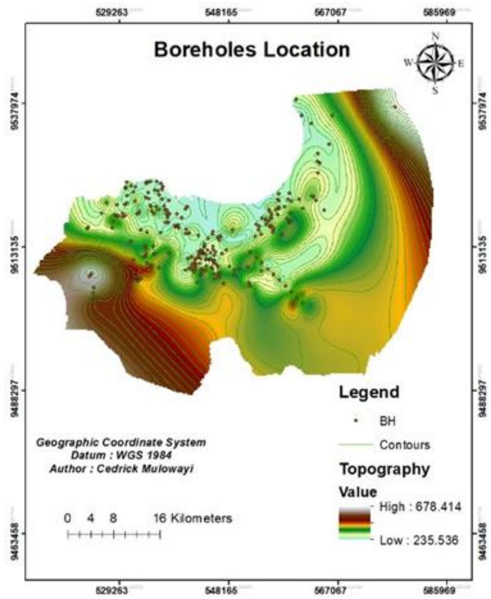


Figure 5: Topographic Map of Kinshasa

Soil Map

According to Nzuzi (2008), the greater part of the city of Kinshasa is covered with a more or less thick mantle of sandy and sandy-clay soils varying in color from yellow, light brown and sometimes reddish. This is endorsed by the soil distribution map of our study area which shows a soil texture classification dominated by Sandclay followed by Sand and by Clay (light) at low percentages as can be seen in Figure 6 below.

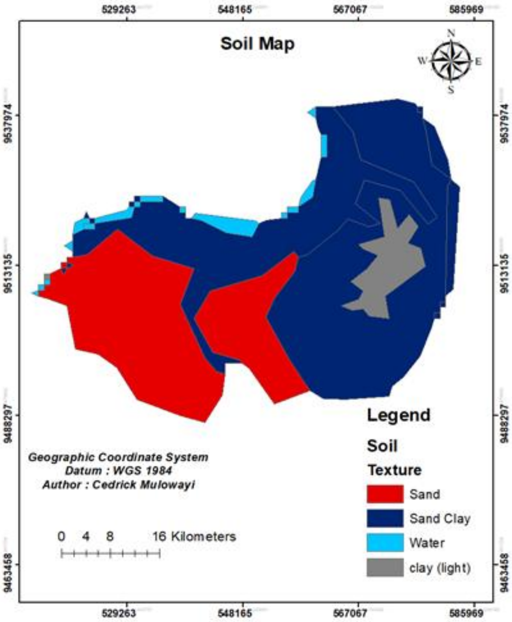


Figure 6: Soil Map Distribution

The soil map distribution shows that Clayey Sand occupies 59.7% of the total area followed by Sand, which occupies 37.7%. The part occupied by the water covers 2.6% and the clay (light) occupies 0.03% as shown in Figure 7 below. This sand-clay occupies the northern part, ie along the Congo River as well as the greater part of the East in which we find the clay (light) while Sand occupies all the South and South-West part as shown in Figure 6 above.

The presence of clay and sand-clay in our study area makes infiltration and recharge variable from one place to another, but with a high recharge rate to the southwestern part with respect to the presence of sand.

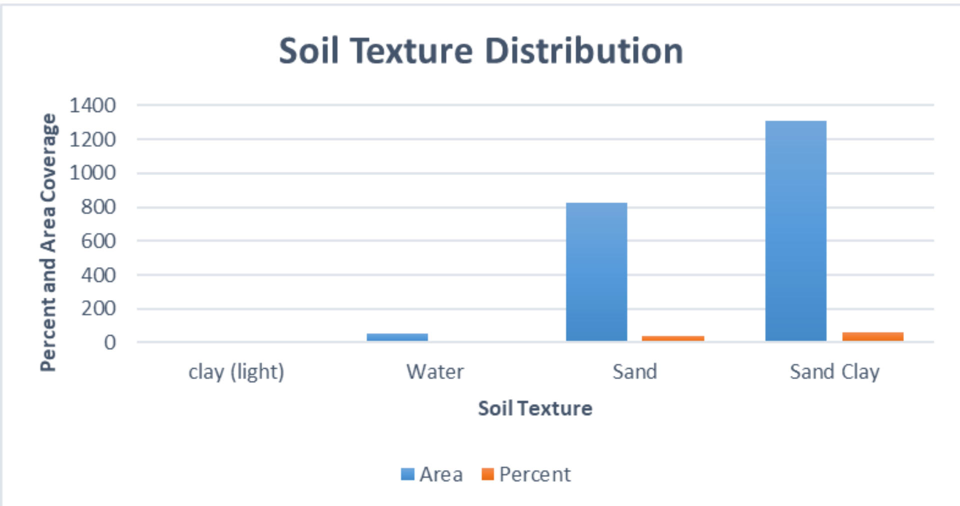


Figure 7: Percentage of Soil Texture Coverage

Slope Intensity Map

The percentage slope has been classified as 0 - 2, 2 - 5, 5 - 10, 10 - 30 and> 30%. It appears from this classification that the areas in the North, more precisely those along the Congo River and those along the N'djili and N'sele rivers, have a low percentage gradient ranging from 0 to 2%, which gives them a high recharge rate. The areas on the North-South axis have a moderately low percentage slope of 2 to 5% while those in the eastern part have a very high percentage slope of ie> 30% and have a low recharge rate as shown in Figure 8 below.

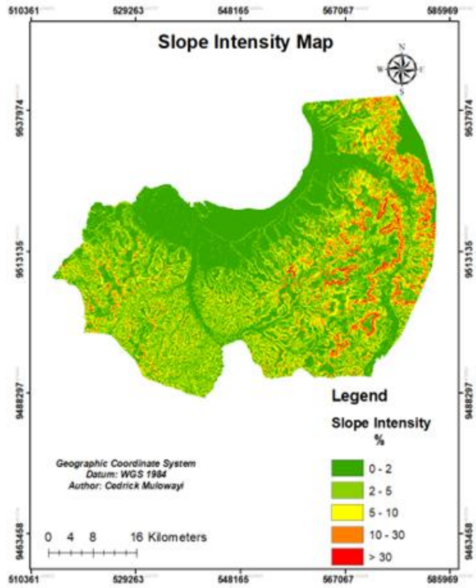


Figure 8: Slope Map of Kinshasa City

Drainage Density System

The classification has been divided into three classes of which: 0.69 - 1.99; 1.99 - 3.00 and 3.00 - 4.53. This classification indicates that areas in the north, more precisely those along the Congo River and those along the N'djili and N'sele rivers, have a high drainage density ranging from 3.00 to 4.53 (km / km^2), and such a higher density of drainage leads to high runoff, hence low infiltration and recharge. Areas in the Center, South and East-West areas of the watershed have moderate to high drainage densities giving them an average recharge rate. Figure 9 below shows the drainage density of the study area.

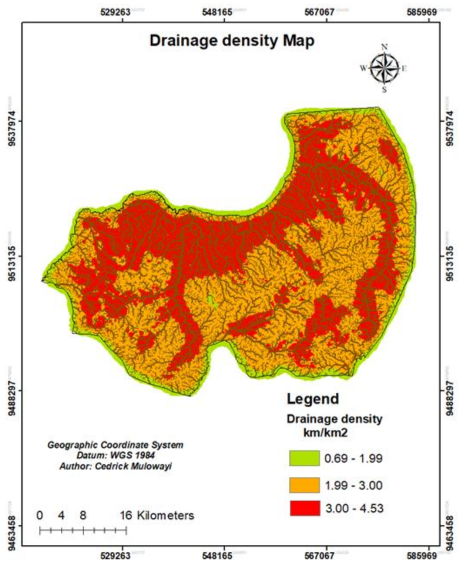
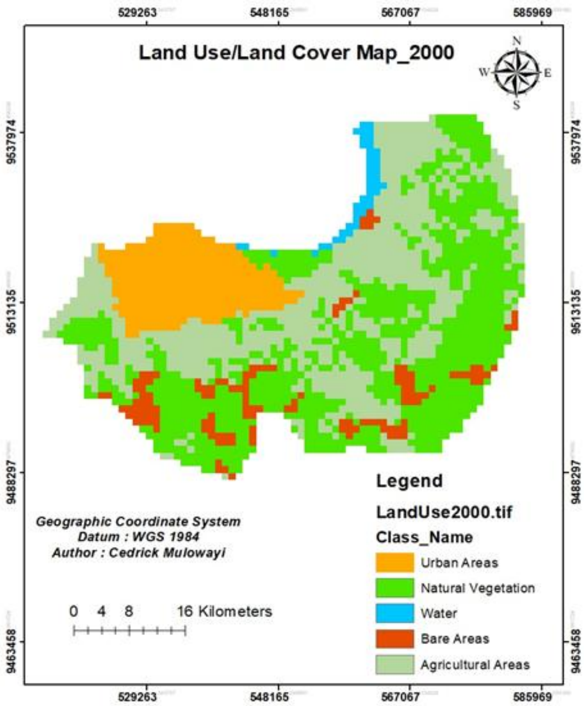


Figure 9: Drainage Density Map of Kinshasa City

Land use/ land cover map

Figures 10 and 11 below illustrate the spatial dynamics of land use/land cover from the year 2000 to 2013. The result from the supervised classification for the LU/LC 2000 established a percentage of 13.4 of the area related to the urban areas, 42.5 for the natural vegetation, 1.9% for water bodies, 6.3 for bare areas and finally 35.9 for agricultural activities. A contrasting picture is shown for the LU/LC 2013 with the result from the supervised classification of 41.3% for the urban area, 20.7% for agricultural activities, 37.4 for natural vegetation and 0.6% for water bodies.



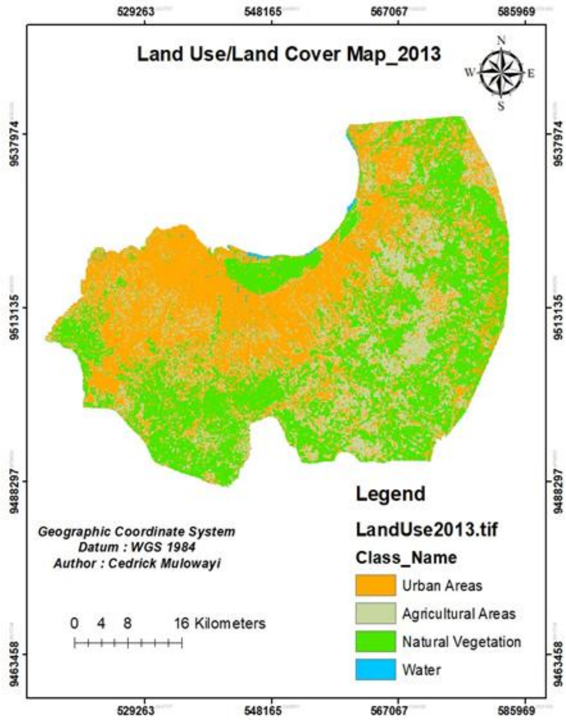


Figure 10: Land Use/ Land Cover 2000 of the Study Area
Figure 11: Land Use/ Land Cover 2013 of the Study Area

It was observed that there was an increase in an urban area which went from 13.4 to 41.3% due to population growth. On the contrary, it decreased respectively in natural vegetation from 42.5% to 37.4%, agricultural areas from 35.9% to 20.7%, and water bodies from 1.9% to 0.6% in Figure 12.

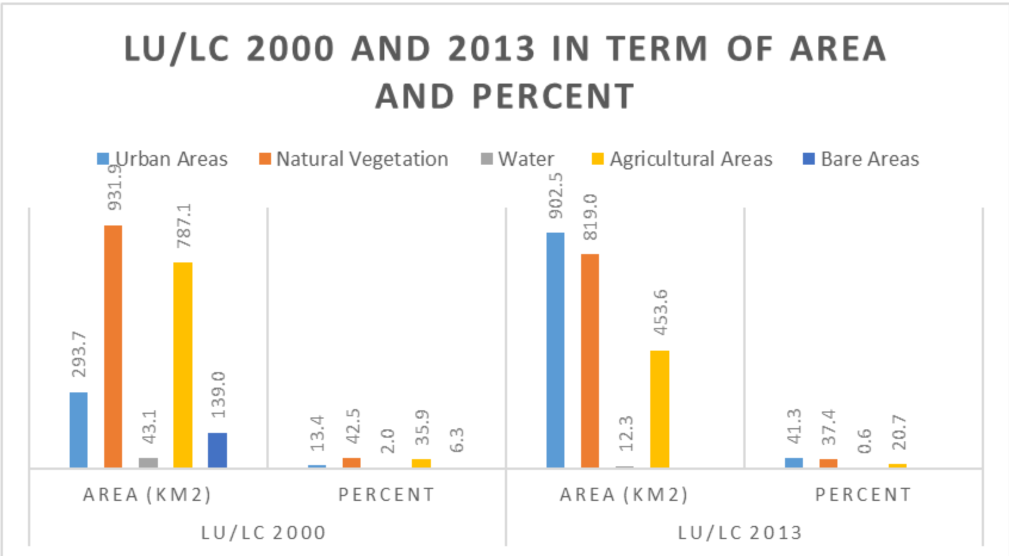


Figure 12: LU/LC 2013 in term of dynamics of area and percent

Runoff

The result of Runoff Map of the Kinshasa city (Figure. 13) shows the highest runoff value which is about 409.085mm as well as the lowest runoff value which is 141.177mm.

All the input data needed to estimate runoff potential had a significant impact on runoff zone of the study area such as: rainfall distribution, digital elevation model (DEM), soil texture and Land Use/Land Cover. To all these input data, it will also be necessary to add the slope intensity because in general, the steeper and longer the slope, the less the soil recharges because there is a strong runoff and the drainage of density.

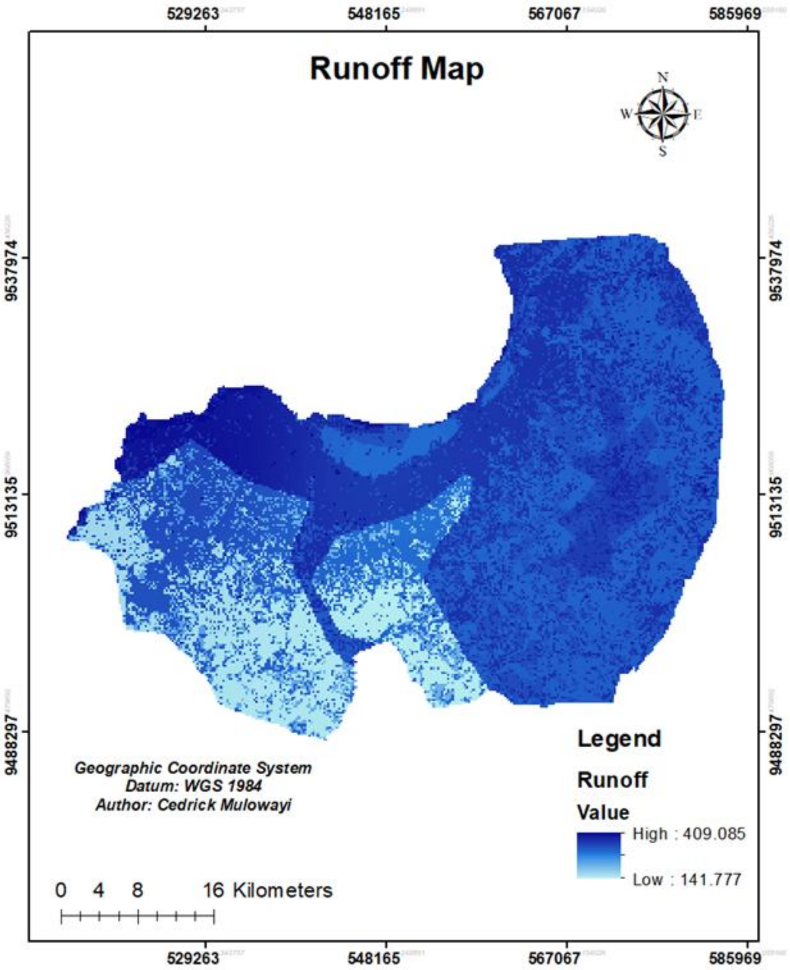


Figure 13: Runoff Map of the Study Area

Recharge

The DEM of Kinshasa Region allowed us to locate the highest points of the study area, among others: Mount Mangengenge located in the eastern part of the Region, followed by Mont Ngafula located in the western part of the region and finally Mount Ngalieme located in the North-West part of the Region.

This aspect had a lot of influence on the one hand, on the intensity of the slope because in general, the steeper and longer the slope, the less the ground is recharged because there is a strong runoff as we can see it in the slope intensity map above (Figure 8) in which; the zones located in the low altitudes more precisely along the Congo river and those along the N'djili and N'sele rivers benefit from a high recharge rate because there is less runoff, while those located in the high altitudes lead to strong runoff and less recharge; on the other hand, on the drainage density which is very high ranging from 3.00 to 4.53 (km / km^2) in areas at low altitudes, more precisely along the Congo river and those along the rivers N'djili and N'sele because it directly receives water from high altitudes leading to high runoff, resulting in low infiltration and low recharge, while areas in the center, south and east-west of the watershed present moderate to high drainage densities, giving them an average recharge rate as shown in Figure 9 above.

As we know from Mahapatra et al., (2020), the soil texture distribution does not have the same rate of infiltration or recharge. Compared to the three soil texture classes found in our area, only sand has a high recharge rate, followed by sandy clay and subsequently clay (light), but our study reveals that the sand occupies just 37, 7% of the 59.7% occupied by sandy clay as shown in Figure 6 an above. This leads to say that the Kinshasa City is dominated by average recharge rate according to the soil texture.

From 1960 to today, this population has grown from 400,000 inhabitants to almost 12 million and is expected to exceed 14.5 million people by 2025 according to statistical projections. This is proved by the spatial dynamics of land use/land cover from the year 2000 to 2013 which illustrate that there was an increase in an urban area which went from 13.4 to 41.3% (a sharp increase of almost 27.9% in just 14 years) due to population growth.

On the contrary, it decreased respectively in natural vegetation from 42.5% to 37.4% (5.1%), agricultural areas from 35.9% to 20.7% (15.2%), and water bodies from 1.9% to 0.6% (1.3) as shown in Figure 12 above.

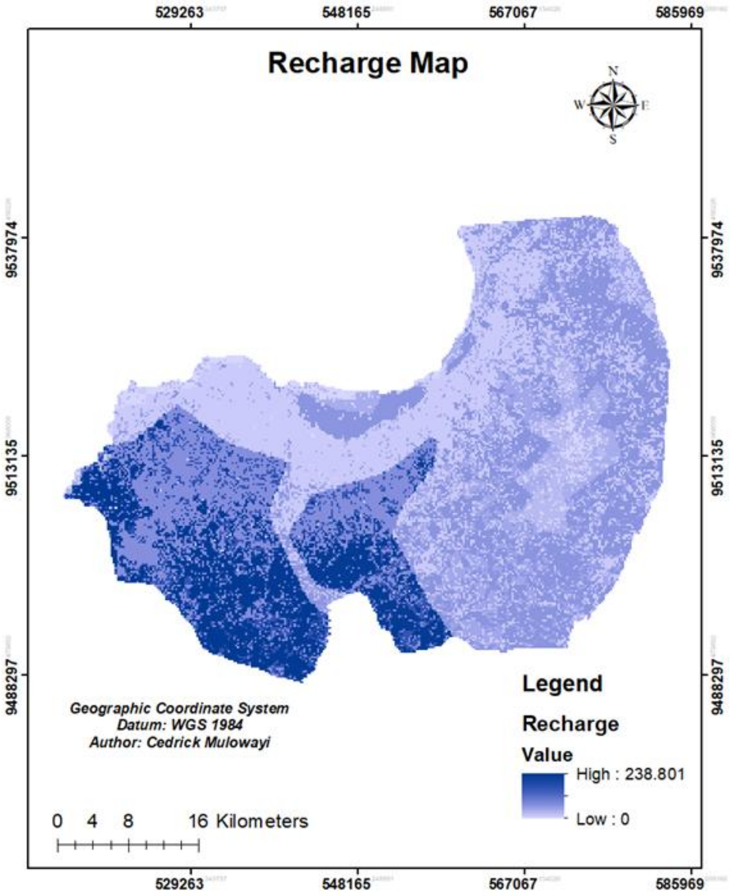


Figure 14: Recharge Map of the Study Area

According to all the figures above, the groundwater recharge is strong in Southwest and less in paved areas and clay-sand soil type to East.

Empirical Method (Groundwater Recharge Estimation, Recharge Coefficient and Effective Rainfall)

According to the U.P. Irrigation Research Institute, Roorkee, the annual recharge of groundwater in our study area using their empirical formula was estimated at 236.21 mm /year, for a period of 2000 to 2013 with the Average Rainfall of 1540.04 mm/year and the Evapotranspiration of 1151.57mm/year, the Effective Rainfall P_e was estimated at 388.47mm/year and the Recharge Coefficient was estimated at 60.8%.

IV. Conclusion

Since several decades now, the population of the Kinshasa Region has been increasing day by day due to migration, civil wars (especially in its eastern part) and the search for better living conditions in terms of work positions, access to the improved health care system, as well as educational opportunities. Thus, the resources necessary for daily life are scarce to meet the needs of this growing population. Among these resources, water resources are also one. Despite being covered by rains for almost half of the year and the presence of the Congo River and its tributaries, the city of Kinshasa has many water resources. However, the availability of drinking water is a challenge for the population. So, groundwater is one of the alternative sources. However, groundwater extraction without proper management may leads to aquifer depletion that's why the estimation groundwater recharge is a very important parameter for the assessment and management of groundwater resources.

Noted that, the overcrowding of the Kinshasa City results in the rapid horizontal expansion of the mega-city, which is driven by chaotic urbanization accompanied by the construction of slums here and there without taking into account the geological constraints of this city.

As we know, the soil texture distribution does not have the same rate of infiltration or recharge. Compared to the three soil texture classes found in our area, only sand has a high recharge rate, followed by sandy clay and subsequently clay (light), but our study reveals that the sand occupies just 37, 7% of the 59.7% occupied by sandy clay as shown in Figure 6 an above. This leads to say that the Kinshasa City is dominated by average recharge rate according to the soil texture.

From 1960 to today, this population has grown from 400,000 inhabitants to almost 12 million and is expected to exceed 14.5 million people by 2025 according to statistical projections. This is proved by the spatial dynamics of land use/land cover from the year 2000 to 2013 which illustrate that there was an increase in an urban area which went from 13.4 to 41.3% (a sharp increase of almost 27.9% in just 14 years) due to population growth. On the contrary, it decreased respectively in natural vegetation from 42.5% to 37.4% (5.1%), agricultural areas from 35.9% to 20.7% (15.2%), and water bodies from 1.9% to 0.6% (1.3) as shown in Figure 12 above.

The results of this study show that according to the U.P. Irrigation Research Institute, Roorkee, the annual recharge of groundwater in our study area using their empirical formula was estimated at 236.21 mm /year, for a period of 2000 to 2013 respectively which is consistent with Arcgis 10.5's calculated recharge value which is between 0 to 238.801mm/year. With the Average Rainfall of 1540.04 mm/year, the Evapotranspiration of 1151.57mm/year, the maximum runoff of 409.085 mm/year, the Effective Rainfall Pe was estimated at 388.47mm/year and the Recharge Coefficient was estimated at 60.8%. These values confirm the study carried out by Ndembo et al., (2007) in the Mont-Amba aquifer which evaluates the recharge at 284.48 mm / year and the evapotranspiration (Penman) at 1200mm / year. About the comparison between the two methods, we think that the GIS method is the best because it requires a number of input data allowing to make a good spatial analysis such as: rainfall distribution, digital elevation model (DEM), slope intensity system, drainage density system, soil texture, land use/land cover and runoff. All these spatial data lead to a good understanding of the recharge system of the zone whereas the empirical method gives only the maximum value of the recharge zone.

In view of all this, it should be noted that the immaturity of urban structures and the absence of structures such as subways, large pipelines and deep foundations of civil structures, suggests that there is no serious human intervention on the regime of shallow groundwater flow. However, groundwater recharge through recharge is changing, especially in the densely populated areas of Kinshasa by the presence of impervious surfaces, such as buildings, paved roads, and existing storm sewers which make the rainfall water (the main source of recharge) take time for the runoff and evapotranspiration rather than infiltrate or recharge.

Finally, according to the maps of this study, the groundwater recharge is strong in Southwest and less in paved areas and clay-sand soil type to East.

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