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**Research Article**

# Study of Digital Surface Data for Soils and Flood Risk Areas Mapping in Sudano-Sahelian Zone (Mayo-Danay Division, Far North Cameroon)

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**Abstract** In general, living close to a river is advantage, but there is always of flooding risk, that recurrence in recent decades provokes serious material damage and loss of life. Thus, in order to protect environmental health, economic viability and human activity zones of Mayo-Danay, a careful study of components of natural environment, mainly soil, has proved essential. Clearly, use of GIS in management of natural disasters is most relevant method, designed on integration, Multicriteria Analysis (MCA) and spatial data. Thus, Digital Elevation Model is obtained by manual digitization of contour lines, in order to define the large pedological sets on which wells have been opened, profiles described, soil samples taken and analyzed in laboratory. Main results reveal that soils are sandy to clayey, with neutral and basic pH (7 to 8), high CEC and low organic matter. While, quartz is predominant, associated with smectites, illites, feldspars and iron oxyhydroxides. Updated soil map shows five soil units (1) vertisols with hydromorphic characters (26%), (2) tropical ferruginous soils (32%), (3) less evolved hydromorphic soils (15%), (4) halomorphic vertic soils (9%), and (5) hydromorphic vertic soils (18%). It is an excellent tool for work and research, that responds to agronomic and development problems. It is therefore an excellent tool for work and research, which responds to agronomic and development problems. The multi-criteria spatial analysis establishes hazard and vulnerability, crossing of which gives of flood risk areas map, according to hazard level, very high (12%), high (16%), moderate (14%), low (30%) and very low (28%) risks. For this purpose, it emerges that rainfall is relatively low (700 mm/year), but falls very abruptly during short periods, at high intensity with flows exceeding the infiltration capacities. Morphology of low-slope "yayrés" (280 m) (2‰) is bordered by high landscape (500 to 1400 m) that prevent flow of many rivers that converge into plain. Sandy soils dominated by quartz favor fast rising in water table, while very clayey soils governed by 2/1 clayey (smectites) whose behavior induce waterproofing and intense surface runoff that generate flooding. Evidently, land use change leads to transformation of natural spaces into

agricultural and urban environments, which makes soils more compact and impermeable, favorable to flooding.

**Keywords** *Soil; Flood risks; Mapping; Mayo-Danay Division; Spatial data*

## 1. Introduction

Recognized to be environment for natural flooding disasters, Mayo-Danay division located in Far North of Cameroon is subject to flooding of various kinds. Particularly, last decade has been impressive with violent rains causing flood phenomena in 2012, 2014, 2015 (Minader, 2012; Leumbe et al., 2015) and most recently in 2019 which caused significant material and human damage and generated considerable economic impact. However, soils in sudano-sahelian zone strongly influence flooding processes through their exceptional properties (Basga, 2015; Leumbe et al., 2015). Optimal management of floods requires a good knowledge of causes of phenomenon and a best mapping of their extension. Therefore, a careful analysis and a good mapping of intrinsic and extrinsic factors of soil will be of paramount importance, to identify role of each pedological variables examined in floods genesis. For a fine, complete, judicious and innovative study, a strong involvement of Geographic Information Systems (GIS) has been implemented with insight of their important scientific and technical bibliography. However, its applications to cartography remain experimental, particularly in North, West and Central Africa (Tchotsoua et al., 2007; Leumbe et al., 2015; Ibrahim et al., 2018). It is indeed following this situation that present study was undertaken in Mayo-Danay division, whose main purpose is to examine in detail digital surface data to realize a soil and risk of flooding areas maps. Specifically, it will be a question of studying intrinsic and extrinsic soil properties and understanding their role in floods genesis, which are a major and constant concern of public authorities and riparian populations.

## 2. Materials and Methods

### 2.1 Study Area

Located in sudano-sahelian zone of Far North Cameroon, study area is between 10°00 and 11°10 North and between 14°50 and 15°40 East (Figure 1). Rainfall varies from 300 to 900 mm/year and temperature is 28°C (Suchel, 1987; Olivry and Naah, 2000). Tree-covered shrubby savannas and periodically flooded grasslands are the main colonizing plant species. With an average altitude of 280 m, study area is part of vast morphological unit identified in Nigeria, Niger and Chad (Barbery and Gavaud, 1980; Sighomnou, 2003). Drainage network is hierarchical around mayos of Mandara Mountains and Logone (Olivry and Naah, 2000). Some geological formations and alluvial deposits of Quaternary constitute substratum, on which several types of soil are formed (Barbery and Gavaud, 1980; Tiki, 2014; Basga, 2015; Ibrahim, 2020; Tiki, 2020). The main activities are agriculture, livestock farming and fishing. Climatic conditions and relief forms are favorable for cultivation of cotton, rice, millet, maize, groundnuts, cowpeas, cassava and fruit trees (Seignobos and Moukouri, 2000).

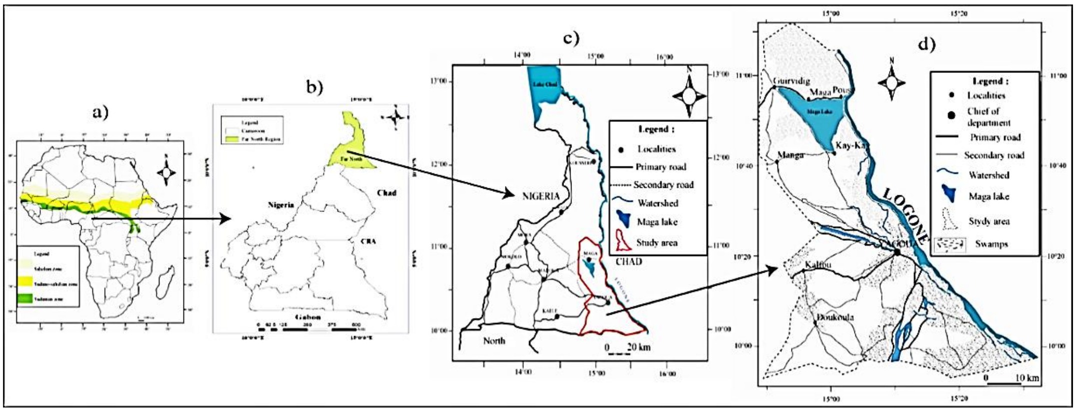


***Figure 1:*** *Sudano-Sahelian zone of Africa (a); Cameroon (b); Far North (c); study area (d).*

## 2.2. Soils Sampling and Analysis

Methodological approach starts with a detailed study of soil variables. It consists of a fieldwork, which was carried out with a topographic map (1/200000). It allowed landscape description, to dig soils pits, morphological characterization and collection of soil samples. In laboratory, physical, chemical and mineralogical analyses (DRX and IR spectroscopy) of soils were carried out in order to draw up a soil map and to highlight properties that influence flooding. Map was refined by contribution of laboratory data and satellite imagery. Latter were processed and then integrated under GIS with contribution of existing data which were extremely beneficial, following methodological model below (Figure 2).

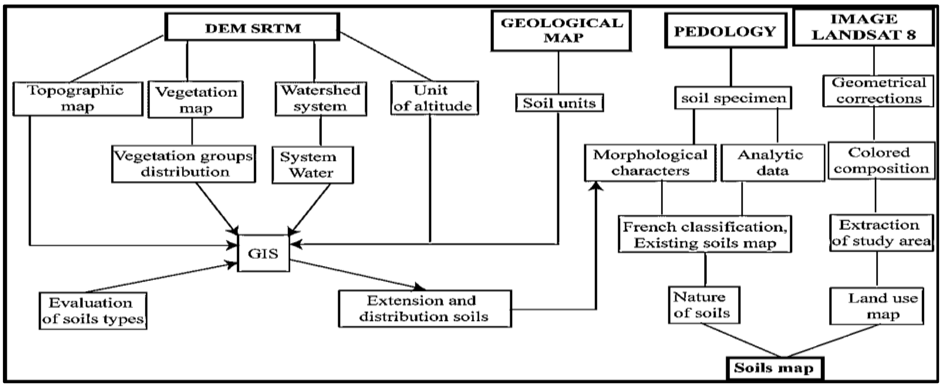


***Figure 2:*** *Methodological scheme for soil mapping*

## 2.3. Database

In order to carry out this study, a database was collected. It is distinguished by climatic data which includes time series of daily, monthly and annual rainfall amounts from rain gauges located in Yagoua and surrounding sites. Geospatial data is *SRTM* (Shuttle Radar Topography Mission) Digital Elevation Model with a resolution of 30 m and on 30 m x 30 m grid were acquired in February 2017. Using *ArcGIS 10.3* software, several metric factors were extracted, including altitude, slope and drainage network. Landsat 8 OLI-TIRS satellite data acquired on site on January 26, 2017 were used for land coverage class mapping and *NDVI* (Normalized Difference Vegetation Index) respectively. These are scenes 184/052 and 184/053. They have been used to discriminate land cover units from which material and human vulnerability maps were derived from land coverage map made on *Envi 4.5*.

## 2.4. Data processing and flood risks areas mapping

Threat mapping requires data, software and methods adapted to knowledge and extension of danger and to optimal management of flood risks. However, use of geomatic is necessary to produce finer, more detailed and well exploitable data. In order to properly flood risks assess, two parameters must be highlighted (Cerg, 2000), hazard and vulnerability, intersection of which (*ArcGis 10.3* and *Envi 4.5*) has made it possible to produce a of flood risk areas map according to methodological model shown below (Figure 3).

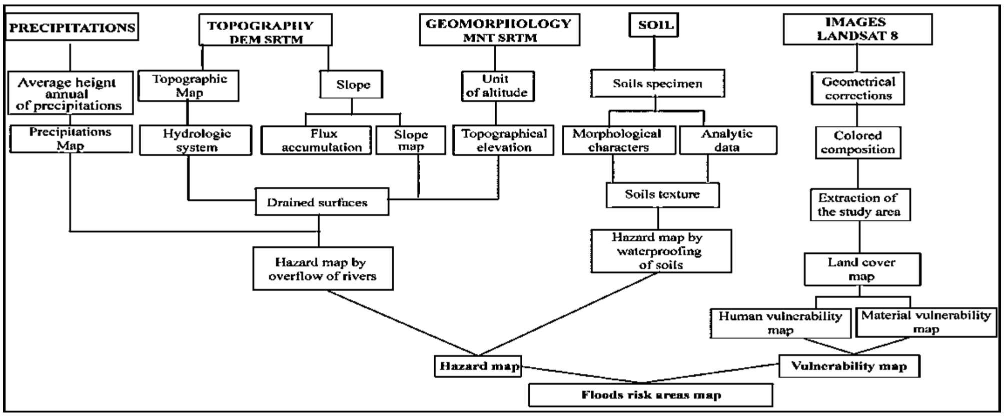


***Figure 3:*** *Methodological scheme for of flood risk areas mapping*

## 3. Results and Discussions

### 3.1 Soil Study

#### 3.1.1. Soil Morphology

Soils are located on flat relief that varies from 300 to 360 m in altitude, where sandy-clayey alluvia predominate (alternating sandy and clayey strips). Vegetation is a shrubby to tree-covered savannah and flooded meadows. On surface, desiccation cracks up to 1 m of depth are visible, with "gilgaï" micro-reliefs type in form of hollows and bumps in the constantly flooded areas, and high hydromorphic proportions.

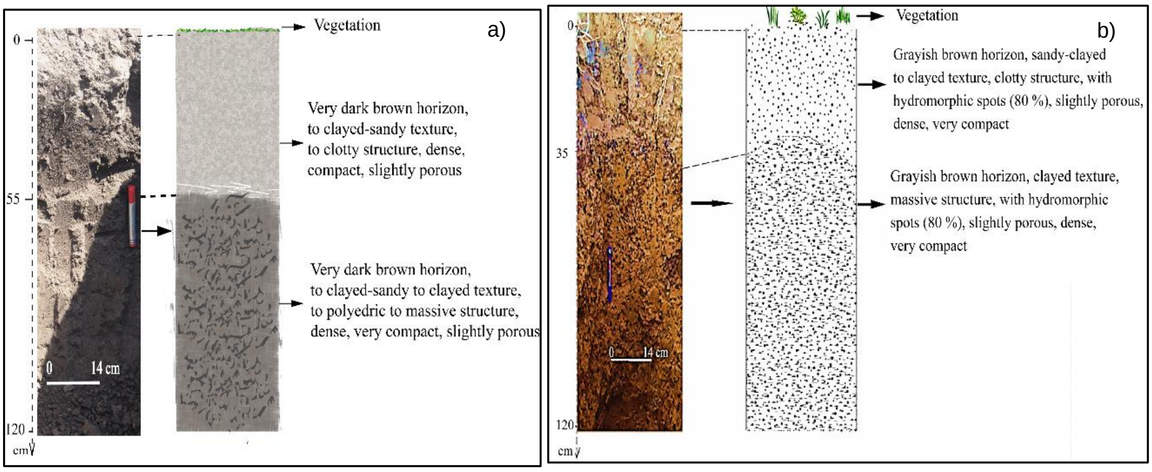


***Figure 4:*** *Morphological and vertical organization of hydromorphic vertisols (a) and hydromorphic soils (b).*

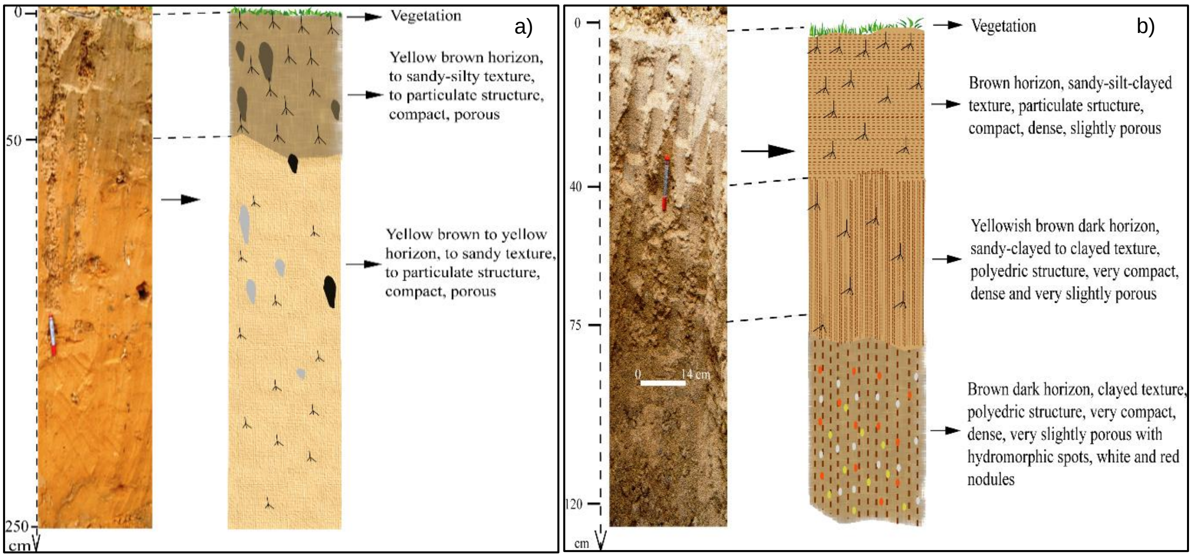


***Figure 5:*** *Morphological and vertical organization of tropical ferruginous soils (a) and halomorphic soils (b)*

The dark brown to greyish brown colors are very manifest, in contrast to yellowish brown color. Massive and particulate structures animate soil profiles. On other hand, sandy soils are very porous, while clayey soils are very compact and dense with a strong presence of hydromorphic spots (Figs. 4 and 5.).

### 3.1.2. Physical and chemical data of soils

***Table 1:*** *Synthesis of physical and chemical data of soil*

| Units of soil | Horizon (cm) | Texture (%) | | | Stable aggregates (%) | RM (%) | pH | OM (%) | Exchangeables bases (méq/100g) : S | | | | | T (meq/ 100g) | S/T (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | S | L | | | | | $Ca^{2+}$ | $Mg^{2+}$ | $K^{+}$ | $Na^{+}$ | S | | |
| Vertisols | 0 – 55 | 47,22 | 29,46 | 23,32 | 91,08 | 6,95 | 6,7 | 0,5 | 1,13 | 0,19 | 0,02 | 0,13 | 1,47 | 27,02 | 50 |
| | 55 – 120 | 48,51 | 40,57 | 10,92 | 82,2 | 9,53 | 7,9 | 0,49 | 1,01 | 0,44 | 0,02 | 0,08 | 1,55 | 32,42 | 70 |
| Less evolved soils | 0 – 30 | 21,76 | 40,63 | 37,61 | 4,27 | 2,04 | 6,4 | 0,61 | 0,64 | 0,09 | 0,02 | 0,05 | 0,80 | 15,7 | 50 |
| | 30 – 100 | 24,96 | 45,39 | 29,65 | 22,45 | 3,41 | 8,4 | 0,51 | 0,06 | 0,05 | 0,05 | 0,67 | 0,84 | 19,24 | 40 |
| Halomorphic soils | 0 – 40 | 52,68 | 16,05 | 31,27 | 85,44 | 5,6 | 8,5 | 0,91 | 1,49 | 0,22 | 0,04 | 0,08 | 1,83 | 26,3 | 70 |
| | 40 – 75 | 36,86 | 13,2 | 49,94 | 73,98 | 7,3 | 9,1 | 0,74 | 1,44 | 0,28 | 0,02 | 0,11 | 1,85 | 26,42 | 70 |
| Ferruginous soils | 0 – 50 | 21,4 | 46,81 | 31,79 | 18,72 | 2,25 | 7,2 | 0,83 | 0,83 | 0,09 | 0,07 | 0,02 | 1,01 | 13,69 | 40 |
| | 50 – 250 | 36,11 | 43,02 | 20,87 | 47,12 | 6,39 | 7 | 0,00 | 0,48 | 0,05 | 0,06 | 0,01 | 0,60 | 17,2 | 60 |
| Hydromorphic soils | 0 – 35 | 20,79 | 51,47 | 27,74 | 26,04 | 14,9 | 6 | 0,71 | 0,98 | 0,15 | 0,02 | 0,09 | 1,24 | 34,75 | 40 |
| | 35 – 120 | 39,13 | 22,85 | 38,02 | 38,04 | 13,2 | 7,3 | 0,51 | 0,64 | 0,18 | 0,02 | 0,01 | 0,85 | 16,88 | 50 |

**RM:** Residual Moisture; **pH:** potential Hydrogen; **OM:** Organic Matter; **T:** Cation exchange capacity; **S/T:** Saturation rate

Analytical data indicate opulence of clayey (20-50%) and sandy minerals (10-50%). Latter have an impact on rate of aggregates stability which remain very high in clayey soils. Residual moisture is very high in hydromorphic and vertisols, given their low position in landscape. Basic pH is distinguished in less evolved and halomorphic soils. Organic matter is very low (< 1%), but sum of exchangeable bases is relatively high, as is CEC in vertisols and hydromorphic soils (Table 1).

### 3.1.3. Soil Mineralogy

Soil mineralogy is characterized by quartz, most dominant mineral; clayey minerals, respectively smectites, illites and kaolinite are also perceptible. However, presence along profile of feldspars, goethite and hematite should be highlighted (Figure 6 and 7).

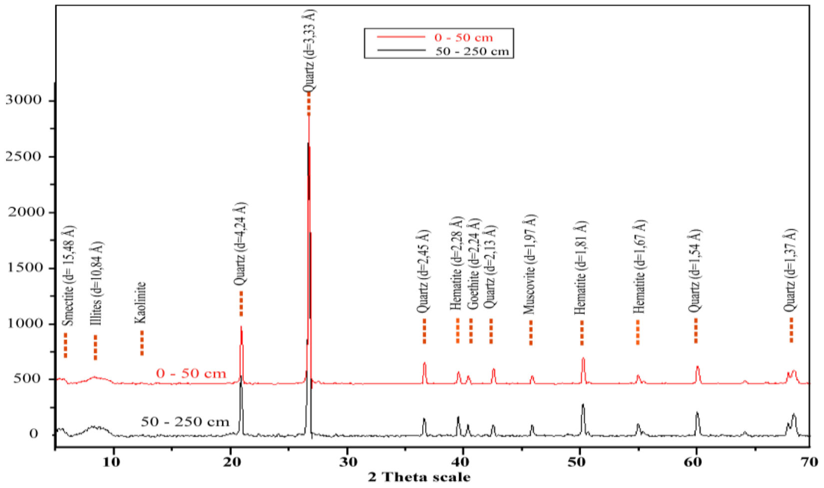


***Figure 6:*** *DRX diagram of ferruginous soils*

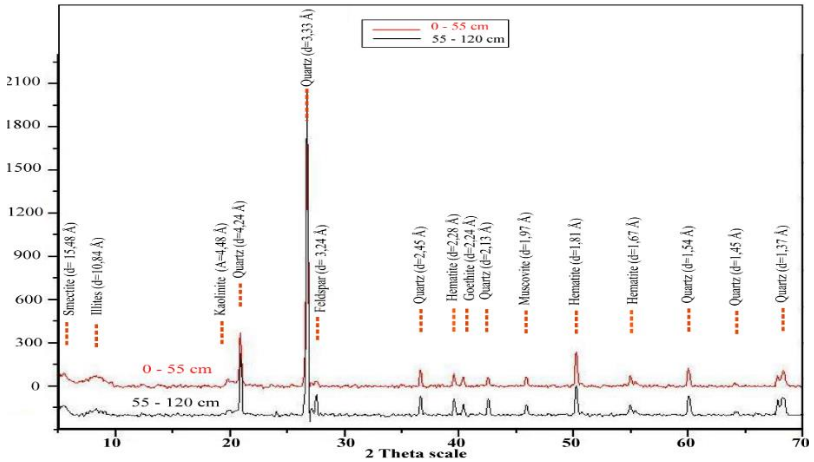


***Figure 7:*** *DRX diagram of vertisols*

IR data indicate that Si-O and Si-O-Al functional groups are respectively characteristic of quartz and clayey minerals (poorly crystallized kaolinite and smectites). Finally, hydroxyl group δOH, characteristic of water is also present (Figure 8 and 9).

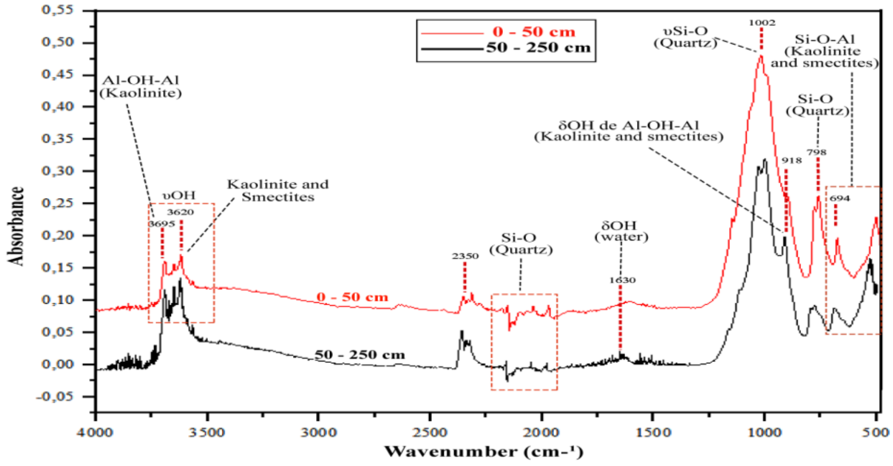


***Figure 8:*** *IR spectrum of tropical ferruginous soils*

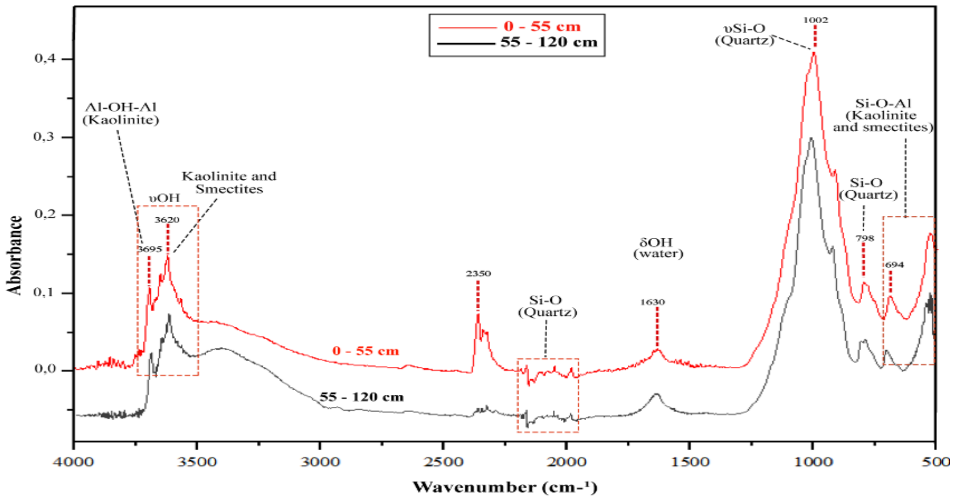


***Figure 9:*** *IR spectrum of vertisols*

### 3.1.4. Soil Map

For a better spatial representation of soil units, careful analysis of factors related to their formation and evolution process is an inevitable workout.

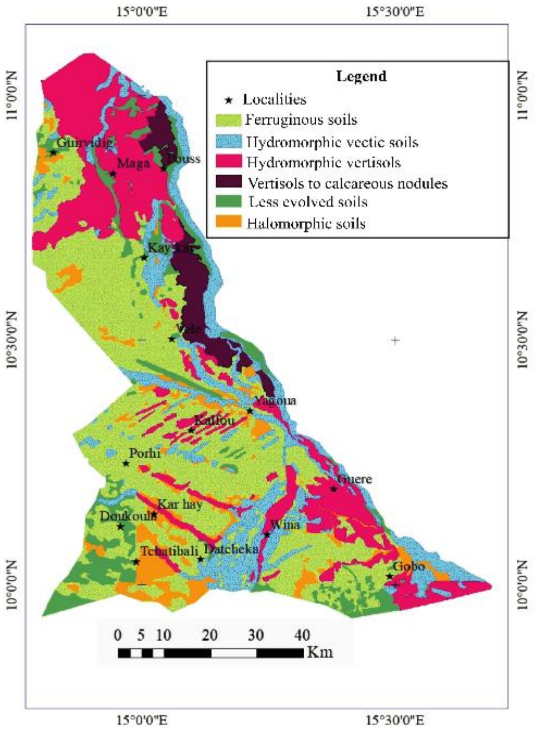


***Figure 10:*** *Soil map (Tiki, 2020)*

It is particularly noteworthy (Figure 10): tropical ferruginous soils (1) are associated with less evolved soils and occupy 32% of study area (1696.96 km$^2$). More visible in the southern and central parts of zone, these soils develop essentially at altitudes between 320 and 350 m, and are dominated by sandy-clayey to sandy alluvia; vertisols with hydromorphic characteristics (2) are organized into two groups, notably hydromorphic vertisols with calcareous nodules located to north and east of study area; and Vertisols without calcareous nodules are generally located in north. They cover an area of 1378.78 km$^2$, of which about 26% is in study area; hydromorphic soils with vertic features (3) represent about 18% of area (954.54 km$^2$) and are located in northern part and along edges of rivers, lake and Logone; less evolved soils with hydromorphic characteristics, associated with halomorphic planosols (4) are located in central, southern and northern parts of study area and occupy about 15% (795.45 km$^2$) ; halomorphic planosols with vertic characters (5) represent 9% of study area (477.27 km$^2$) and are formed at about 320 m (altitude) in degraded areas with sparse vegetation.

## 3.2. Mapping of flood risk zones

### 3.2.1. Hazard map

Natural factors highlighted for hazard expression are climate, geomorphology, slope, hydrography and soil (Leumbe et al., 2015; Ibrahim et al., 2018; Tiki, 2020). Thus, three levels of hazard are perceptible, namely high, medium and low (Figure 11): high hazard occupies about 30% of the total area and is located in north of study area; medium hazard occupies 35% of area and is distinguished in south of study area; low hazard occupies 35% of area and is located in southern and western parts.

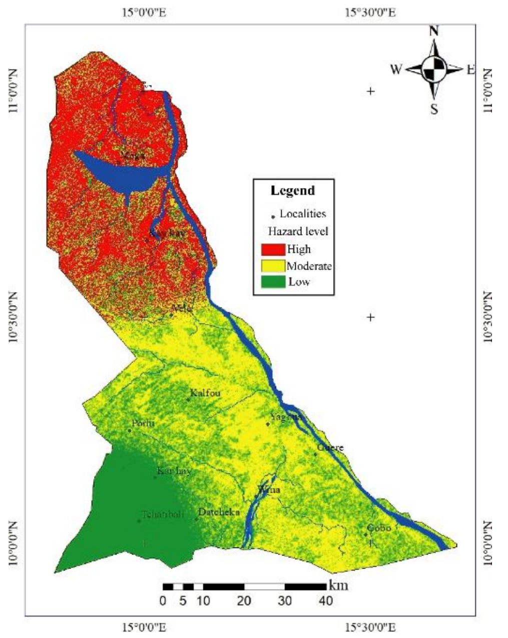


***Figure 11:*** *Flood hazard map*

### 3.2.2. Vulnerability map

Vulnerability is established essentially by land coverage map (buildings, cultivation areas, vegetation, bare soil, etc.) which affects physical and material integrity of human. These factors were analyzed and coefficients allowing associating them were then determined by statistical analysis of damages evaluated during recent floods.

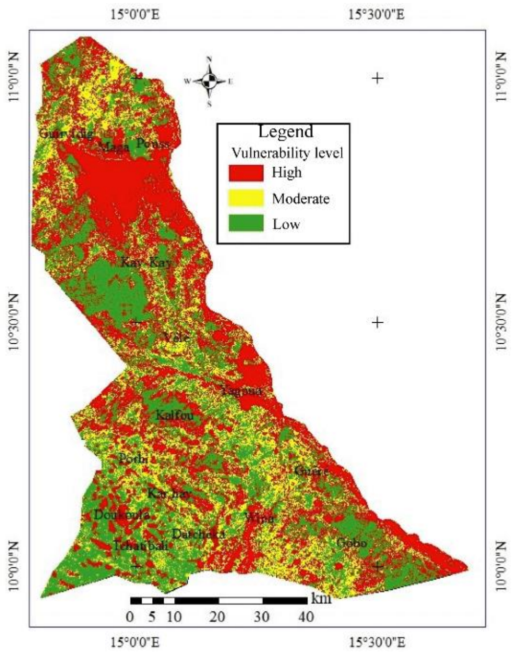


***Figure 12:*** *Vulnerability map (Landsat image 8 OLI-TIRS-2017)*

Thus, high, medium and low vulnerability areas were distinguished (Figure 12): high vulnerability, with a surface area of 2227.26 km$^2$ (42%), it expresses the vigorous fragility class where man is highly exposed to flood risks. It occupies northern, southern and eastern parts; medium vulnerability represents class where delicacy is moderate. Its surface area occupies 18% of study area (954.54 km$^2$); low vulnerability is identified in south and west of study sector and occupies 40% (2121.2 km$^2$).

### 3.2.3 Flood risks areas map

Flood risks areas map shows five specific risk classes according to degree of dangerousness.

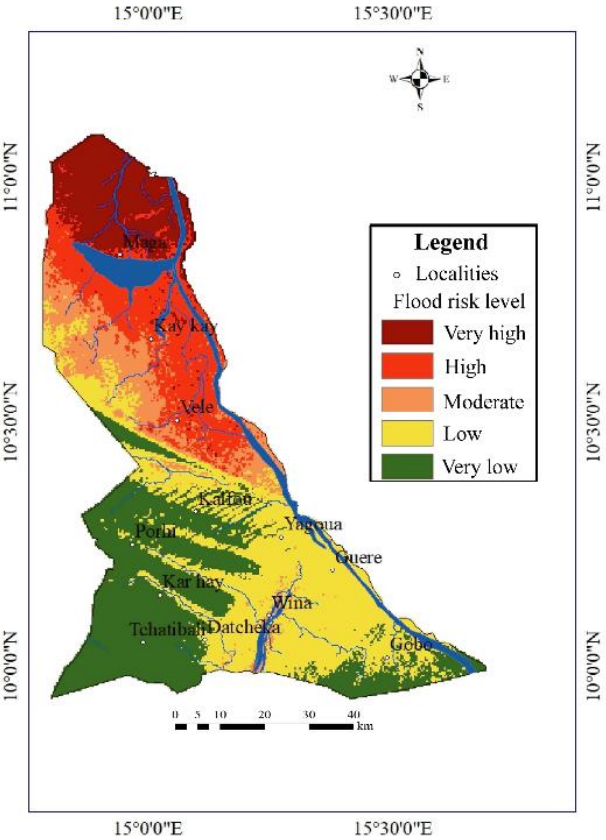


***Figure 13:*** *Map of flood risk areas*

Thus, it distinguishes between very high, high, moderate, low and very low risk areas (Fig. 13): very high-risk areas occupy 12% of study area (636.36 km$^2$), and delineate areas where permanent human settlement is not recommended unless significant precautions are taken. They extend into northern part; high-risk areas represent where sensitivity to flooding risks is high. Covering 848.48 km$^2$ (16%), they occupy areas where human presence is not highly recommended; moderate-risk areas occupy 14% of study area (742.42 km$^2$). In principle, these are areas where permanent human settlement remains possible, but specific precautions are recommended; low-risk zones occupy 30% of study area, precisely 1590.9 km$^2$. By way of recommendation, they symbolize areas for which permanent human settlement is advisable, but precautions remain essential; very low risk areas are defined as zones where threat is insignificant, occupying 28% of study area (1484.84 km$^2$). Permanent human settlement is possible here, but specific precautions are recommended.

## 3.3. Soil and Flood Occurrence

### 3.3.1. Soil Nature

Soil is intimately linked to water through its intrinsic and extrinsic properties, which strongly influence flooding processes. Simple exercise of superposition soil and flood risk areas maps has thus made it possible to identify role of soil variables in floods genesis. Soils are essentially formed on alluvial formations (*"yaeres"*), located at variable altitudes, where permanent processes of water are characteristic of their formation and evolution. Sudano-sahelian climate imparts to soils rather particular characteristics such as formation and alternation of "gilgaï" micro-reliefs, which play a fundamental role in soil genesis processes (Duchaufour, 1977). These micro-reliefs create intense mechanical soil properties, followed by mixing of constituents and poor drainage, where evaporation is important and confinement is rule (Barbery and Gavaud, 1980; Basga, 2015; Ibrahim, 2020). Similarly, seasonal contrast marked by long dry season (8 months) contributes to soil dryness and formation of desiccation cracks. Thus, after closure of desiccation cracks during first rains, water concentrates in surface horizons and immediately subjects soil to intense surface runoff (Barbery and Gavaud, 1980; Montoroi, 2012). Water infiltration into hydromorphic vertisols decreases as result of their surface condition and internal morphology; therefore, surface runoff risk is increased. Clayey character of soil, massive to polyhedral structure, high compactness and very low porosity of horizons of hydromorphic vertisols strengthen their impermeability (Duchaufour, 1977; Barbery and Gavaud, 1980; Leumbe et al., 2015; Tiki, 2020).

Vertical organization of profile shows that they are moderately deep (more than 2 m), and horizons are well differentiated with progressive limits. Soils to south are yellowish brown to light brownish grey (to dark), sandy to sandy-clayey-silt texture, with very dominant particle structure; this can be explained by material movements and slow internal drainage (vertical leaching). Sandy texture predisposes soils to high permeability because of its low water retention capacity; this can thus cause rapid saturation of water table and flooding by rising water at surface (Duchaufour, 1977; Barbery and Gavaud, 1980; Leumbe et al., 2015). Moreover, high porosity and particle structure condition vertical infiltration of water from upper to lower parts (Montoroi, 2012; Tiki, 2020). Hydromorphic vertic soils are more dominant in north of study area and along the edges of Logone. Dominant clayey minerals (47%) come from alluvial deposits and are closely related to organic matter; this makes them well stable (80%), well-structured and very impermeable. This is due to their low position in landscape (300 m) where they are subject to poor drainage, regular stagnation of water in soil and frequent biological activity. Thus, physical data show that these soils quickly become saturated as soon as first rains begin, and are for most part subject to poor water infiltration into soil; consequently, excess water is no longer absorbed (Montoroi, 2012; Leumbe et al., 2015). Low organic matter (< 1%), high moisture content (14%), remarkable CEC (30 meq/100g) and high $Ca^{2+}$ content further increase impermeability of water in soil. Spatial extension of soil in landscape slows down horizontal transfers of surface water according to toposequence, soil cover and model organization. Thus, their distribution along landscape facilitates water runoff according to toposequences (Ibrahim, 2020; Tiki, 2020).

Southern domain of study area, where tropical ferruginous soils (32%) and less evolved soils (15%) predominate, is very little subject to flooding hazards. Sandy minerals (40%) are more dominant, thus they are not very stable (40%) with low humidity (Tiki, 2014; Leumbe et al., 2015). Also, organic matter, sum of exchangeable bases (1 meq/100g) and CEC (15 meq/100g) are relatively low. In agreement with Brabant and Gavaud (1985), Raunet (2003) and Tiki (2014), these results would essentially be consequence of predominance of sandy minerals in these soils, which would indeed favor better vertical and lateral drainage, contrary to vertisols identified in North (Tiki, 2020). This influences water retention capacity of soils. Consequently, soils in southern part would be subject to best water infiltration, consequence of permeability. Thus, water absorption and high landscape position (340 m) of soils is a key factor in near absence of flooding in southern and western zones (Tiki, 2020).

Mineral constituents of soil influence in water retention as each mineral has a specific surface area that interacts with it.

Dynamism of smectite group minerals: soils in intertropical zone indicate presence of smectites, characteristic of soils in poorly drained environments. They have a hydrodynamic behavior that leads to formation of "gilgaï" micro-reliefs on soils surface, as well as remarkable desiccation cracks at depth

(Duchaufour, 1977). Their specific surfaces are good, which gives them a high potential for shrinkage, swelling and mobility (Basga, 2015; Tiki, 2020). They also release bivalent cations $Ca^{2+}$ and $Mg^{2+}$, which play an important role in soil aggregation and structuring. Potentially, they bind water by adsorption and increase in volume by swelling by about 30%; this is why surface cracks fill up during flood periods, resulting in wetting of accumulation horizons, which causes soil to swell, closure of cracks and very sharp decrease in surface porosity. From then on, soil becomes saturated with water and its infiltration capacity is reduced, profile becomes asphyxiating. Immediately, rainwater is concentrated in surface horizons because the highly water-saturated accumulation horizon slows down infiltration considerably. This could lead to intense surface runoff and flooding due to lack of infiltration.

Illite Group: Water can enter the inter-foliar space, causing them to increase from 10 to 14 Å. Studies have shown that illites are dry clayey, with increasing arrival of water, water-clayey assembly becomes plastic, then viscous and finally clayey particles disperse in water forming colloidal solution (stable suspension of particles small enough to make mixture homogeneous). Water-impregnated clayey dries out, shrinks and breaks through shrinkage cracks (Hower and Mowatt, 1900). Unlike smectites, illites are the non-swelling phase of the soil.

Crystalline disorder of kaolinite: clayey minerals of type 1/1, especially kaolinite, have no substitution between layers; therefore sheet is neutral. Indeed, in hydroxyl valence vibration domains (IR data), the simultaneous existence of vibration bands at about 3667 and 3651 $cm^{-1}$ is characteristic of well-crystallized kaolinites (Cases et al., 1982). As crystallinity decreases, the 3667 $cm^{-1}$ band gradually disappears, preceded by inversion of maxima of bands at 3651 $cm^{-1}$ (Fialips, 1999). Thus, poorly crystallized kaolinite behaves like 2/1 type mineral, a very fine clayey. It would immediately contribute to clogging of desiccation fissures identified on surface.

Inactivity of quartz: mineralogical material is very dominated by quartz, to which muscovite is added. Basically, quartz is neutral mineral, it is inactive towards water. Thus, water percolates rapidly through horizons.

### 3.3.2. Rainfall

In general, planet earth is very vulnerable to climate change and variability. When rain falls on soil surface, it is subject to runoff as soil is very quickly saturated with water or is already saturated with water. Flooding by runoff is generally linked to intense (650 and 850 mm/year) and localized rainfall (Figure 14), of high intensity and associated with flows exceeding infiltration or entry capacities of sewerage system (Montoroi, 2012). On physical level, energy of raindrops hitting soil surface causes "splash" phenomenon of which dissociates solid, mineral and organic particles from each other (disaggregation and dispersion). Thus, finest particles clog poral space by forming a crust called "structural", increasingly impermeable to water. Consequently, soil surface goes from structured and porous state to dispersed and compact state (Montoroi, 2012). If rainwater is abundant, it fills tides and forms first floods in lowlands (Olivry and Naah, 2000; Montoroi, 2012; Leumbe et al., 2015; Tiki, 2020).

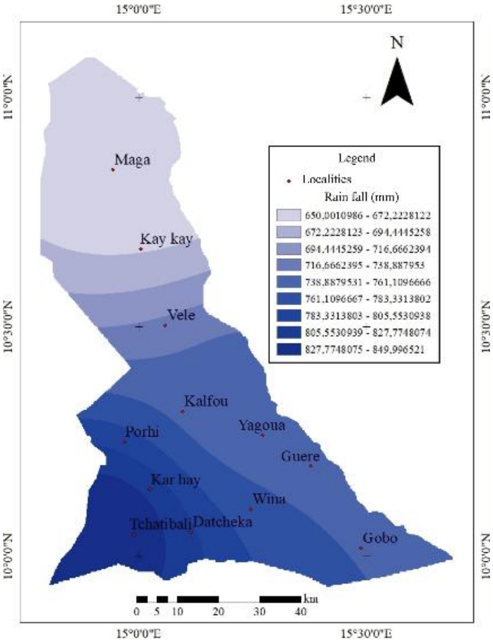


***Figure 14:*** *Rainfall distribution map*

### 3.3.3. Geomorphology

Floodplain is functional of rivers, mainly resulting from precipitation. These put in place mineral elements that shape landscape, dominated mainly by sandy ergs of Kalfou and Limani-Yagoua dune belt. Upstream, sandy alluvia (400 m) is most dominant, followed by alternating sandy-clayey to sandy-clayey. Contrary to downstream (280 m), more precisely on edge of Maga Lake, permanent rivers (Tsanaga and Boula mayos) contribute to alluvial deposits of a clayey nature as shown in figure opposite (Figure 15). Impact of basin morphology in water flow processes is considerable. Altitudinal organization of area reveals three levels of altitude, so study area can be identified as lowest (300 m). Thus, basin structure subjects plains to important water spills from Logone and mayos of Mandara Mountains, which during exceptional floods are cause of overflow floods. Logone plain is bounded to west by Mandara Mountains on border with Nigeria, which culminate at 1494 m above sea level, characterized by steep slopes, vigorous incisions and rivers that compartmentalize them; they discharge all flood waters into floodplains, which can promote onset of floods (Olivry and Naah, 2000; Leumbe et al., 2015; Tiki, 2020).

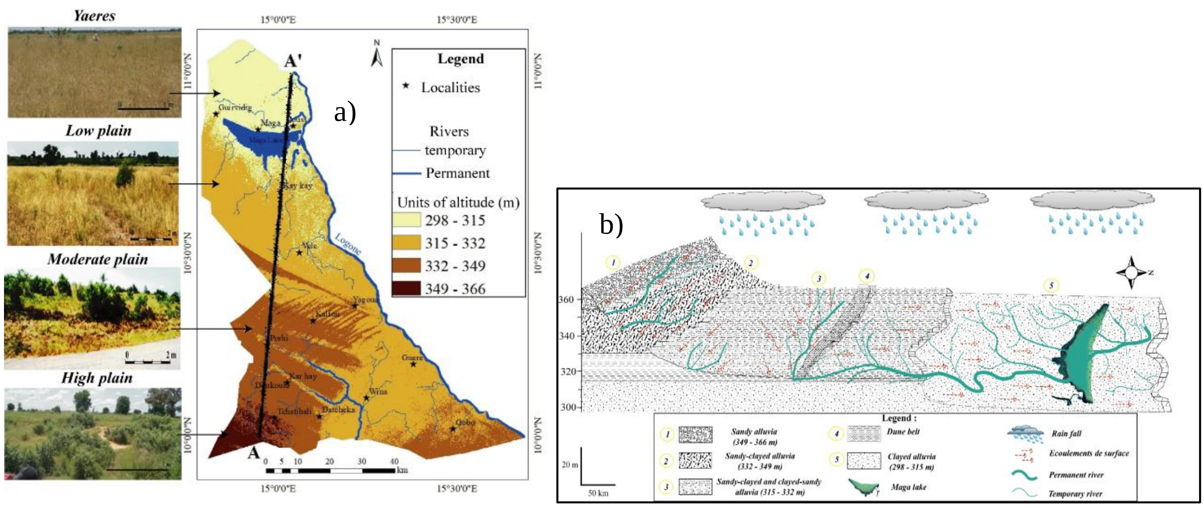


***Figure 15:*** *Geomorphological (a) and hydrogeomorphological organization of floodplain (b)*

### 3.3.3. Slope

Landscape is a plain with low slope values (0 to 25%). Topographical factors act instantaneously on runoff process which modifies soils morphology and surface properties. Slope of study area is almost nil at regional scale.

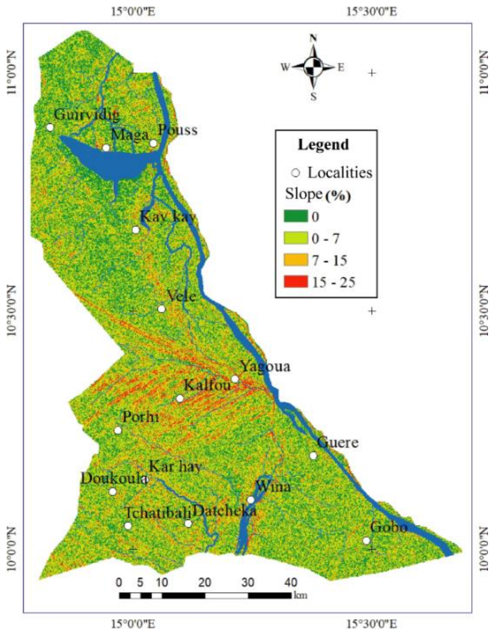


***Figure 16:*** *Slope map (SRTM-2017 image)*

Slope inclination of watershed's slopes affects speed of water flow, while its length favors concentration of important water flows (Olivry and Naah, 2000; Montoroi, 2012). Once in plain with a very low slope, water discharge is influenced by existence of dune barrier and bars downstream actually close off plain and hinder downhill flows of Mandara and Kaélé pediplains (Olivry and Naah, 2000; Leumbe et al., 2015; Ibrahim, 2020; Tiki, 2020). In addition, gentle slope exposes soils to very slow, if any, surface drainage and makes it difficult to evacuate runoff water (Figure 16).

### 3.3.4. Drainage

Organization of drainage system indicates presence of two large watersheds, including Lake Chad and Niger (Figure 17).

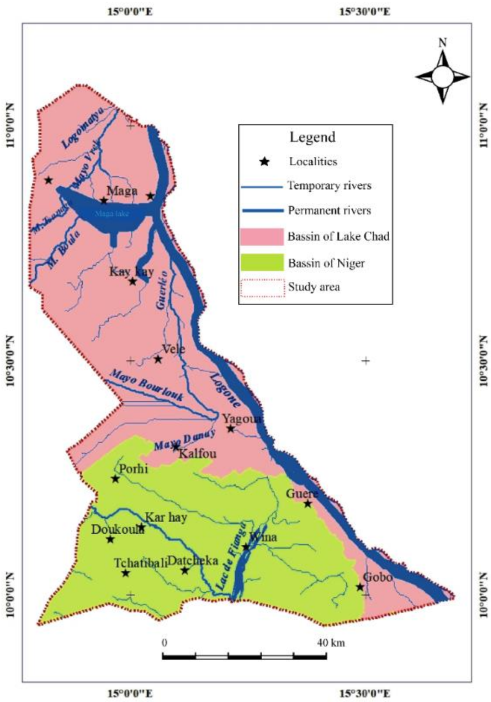


***Figure 17:*** *Drainage map (Image SRTM-2017)*

Approximately 8 million $m^3$/year of water from Logone River are captured by developed water intakes; Maga Dam retains its annual withdrawal capacity of 625 million $m^3$ of water while 144 million $m^3$ of water is withdrawn for SEMRY's rice cultivation needs annually from Logone in Yagoua zone. It should be noted that average volume of water in Logone, which passes through is 17 billion $m^3$ from Bongor to outlet from September. Moreover, it is month in which this river overflows, bringing largest mass of water of 3 to 4 billion $m^3$ for each hydrological year to floodplain (Olivry and Naah, 2000) (fig. 17). Mainly fed by Benue sub-basin, Niger basin follows communion of discharges from the Mandara Mountains, Mayo Kebbi and waters of northern edge of Adamaoua Highland at about 1300 m altitude and only a few kilometers from curves of "cliff". Benue sub-basin supplies study area with significant discharges. Thus, flooding in "*Yaérés*" begins when flows of Logone at Bongor reach 400 $m^3$/s (Olivry and Naah, 2000).

### 3.3.6. Land cover

Logone floodplains are suitable areas for development of economic activities, which contribute to anarchic occupation and misuse of land. Rural exodus of populations to urban centers is transforming agricultural and forest soils, not only through construction of new real estate infrastructures but also through more intensified land use (Montoroi, 2012; Leumbe et al., 2015). Economic and demographic growth calls for technical improvements, through hydraulic improvements to agricultural systems, so that production can cover local, regional and national markets. Thus, form of seasonal and intermittent use of areas rich in silt has, over years, given way to a habitat implanted in an unthought-out manner and, above all, not adapted to floodable environment. Moreover, in urban centers, anarchic settlement of populations in low landscape position, inappropriate for human settlement, and inadequacy of sewerage and rainwater drainage networks are all factors that amplify flooding (Figure 18). Thus, in large cities, some populations settle in lowlands, swamps and riverbeds that are natural refuges for runoff water (Leumbe et al., 2015). However, deforestation by human action over large areas changes drainage system by reducing water storage capacity, as vegetation plays an important role in infiltration by retaining falling water and reducing runoff speed. It accelerates artificial waterproofing of surfaces (roads, parking lots, roofs, etc.), which leads to collection of rainwater by appropriate sanitation networks. Approximately 80% of population lives from agricultural activities. Thus, the agricultural activities (SEMRY) developed lead to modification of natural landscapes, soils transformation and also detour of watercourses. Similarly, rudimentary techniques used in agriculture contribute to soil destructuring and consequently to a poor response to floods (PANA, 2007; Leumbe et al., 2015; Bouba, 2017; Ibrahim, 2020; Tiki, 2020).

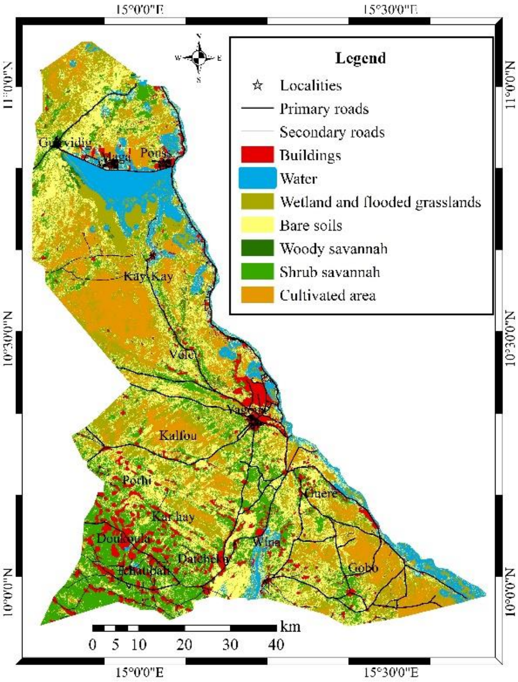


***Figure 18:*** *Land use map (Landsat image 8 OLI-TIRS-2017)*

In lowland areas, generally, soils are subject to intense sheet erosion that slowly scrapes humus-bearing horizon, impoverishing it in fine particles leaving only a skeleton of sandy (Boukar, 2008; Basga, 2015; Tiki, 2020).

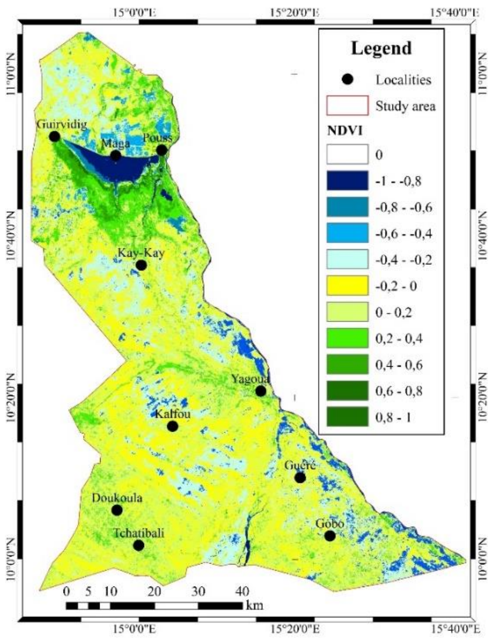


***Figure 19:*** *NDVI Map (Landsat image 8 OLI-TIRS-2017)*

This fragility is due to weak presence of plant formations (savannahs and grasses), as reported by the NDVI map (Normalized Difference Vegetation Index). Indeed, the analysis of NDVI shows that plant cover through chlorophyll activity is very weak in study area. However, water signatures are weakly present in contrast to enormous density of bare soils with sparse vegetation (Figure 19); this favors erosive effect of first rains, leading to considerable loss of land. Furthermore, soil particles are drained and deposited in Maga Lake and Logone River, which contributes to silting and malfunctioning of drainage system (Montoroi, 2012; Leumbe et al., 2015; Tiki, 2020).


***Figure 20:*** *Soil erosion at Yagoua (a), banks of Logone River (b, c))*

Most recently in 2019, Emergency Flood Control Program contributed to greening of area with planting of 6150 trees. This will slow down erosion processes and promote infiltration and circulation of water in soil (Tiki, 2020). Hydraulic structures (Maga reservoir and Vrick mayo spillway) managed by SEMRY were built in 1970s and have not been sufficiently maintained. When lake level began to rise dangerously, it was difficult to open gates. This inability to anticipate and manage floods is in itself a risk to facility. Lake is expected to be partially emptied in July to accommodate rainy season. This would also make it possible to limit lake silting. Pouss spillway should discharge water in one direction or other depending on level of lake or Logone (Mora-Castro and Saborío-Bejarano, 2012; Leumbe et al., 2015). According to reports of consulting firms the Competing-Bet (2006) and ERE-Development (2012), Maga-Vrick-Logone system are highly exposed and subject to gullies action, erosion, whipping (degradation of banks by waves) and effects of swells (large waves), foxes (cracks or holes). In addition to these difficulties, there is climatic bad weather, erosion, silting and progressive raising of bottom Lake, silting of water supply and drainage channels, etc. These degradations clearly disrupt integral functioning of system (Mora-Castro and Saborío-Bejarano, 2012). Finally, lack of forecasting and warning systems, and lack of an effective prevention and warning system at level of land cover and urban planning are organizational causes that increase flooding vulnerability. However, rehabilitation of spillway leading to Mayo-Vrick River, which was recently carried out by flooding project (2019), has made it possible to limit recurrent flood overflows. In addition, raising of Maga dike by 50 cm, as well as that of Logone, has favored reduction of water in plains (Tiki, 2020).

## Conclusion

Study of environmental factors and soil parameters sufficiently demonstrates sensitivity of flooding's area, where several activities are effectively developed. Thus, soils with clayey texture, massive structure (polyhedral), compact and low porosity, are impermeable and subject to intense surface runoff. Alternating desiccation and wetting of soil induced by 2/1 clayey (smectites) induces surface layer of soil and makes it more compact and impermeable. In contrast, soils with sandy texture and particle structure are very permeable and become saturated quickly; quartz, which is most dominant mineral, remains inactive and promotes percolation and circulation of water in soil. Low vegetation cover and slope of watershed further promote flooding. Precipitation is intense and concentrated over only four months, which further increases risk. Land use change in this environment, which results in transformation of natural spaces into agricultural and urban environments, further accentuates impermeability of soil directly related to flooding phenomenon.

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