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CROSS-BOUNDARY HYDRO-GEOLOGICAL RISK ASSESSMENT OF THE LAKE NYOS REGION, NW REGION OF CAMEROON

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ABSTRACT
The existence of a lake is often considered as a potential threat to its immediate surroundings. These threats can be of various forms ranging from flooding, airborne diseases, toxic gas emissions, to disease transmission through insect bites. Lake Nyos, a crater lake in the North West Region of Cameroon poses a number of threats to its immediate surroundings. A multitude of spatial data was employed to assess these threats given the complexity of the geophysical nature of the region. With water accumulation estimated at 3 billion m3, Lake Nyos witnessed a gas explosion in 1986 which led to the death of 1786 people. A lot of research was carried out in order to determine the origin of the gas which confirmed that the gas explosion was of volcanic origin, coming from the mantle through fissures. Field observations were organised in order to define the extent of the gas movement, validate field data, determine the lineaments and make an appraisal of the risk zone which extends into neighbouring Nigeria. This information was then later analysed in the laboratory. Multi-source data (topographic maps, aerial photographs, satellite images, SRTM data) were compared and used to generate DEM lineaments. This revealed that there exist a pyroclastic dam (natural dam) at the southern tip of the lake where water at times flow when it is full, but in case this dam ruptures and/or another gas explosion occurs destroying the natural protectors of the lake water, the floods that will result may spread from Cameroon into Nigeria through streams and troughs putting the lives of about 10,000 people in danger between the two countries.

1. THE STATE OF THE PROBLEM

Since the appearance of the Nyos Crater Lake some 70 000 years ago, the geo-physical risks that loom the area actually became precised in the 1980s. These risks include firstly, the emission of toxic gases from the lake which can be so devastating to human lives and whose frequency has not been determined, and secondly, tectonic activities that can lead to a complete collapse of the pyroclastic dam that holds the lake water leading to ravaging floods that can spread from Cameroon into Nigeria.

The Lake Nyos region lies along the Cameroon Volcanic Line(CVL) that is made up of outcrops of igneous rocks with steep slopes and highly dissected troughs. The name

"Cameroon Volcanic Line" (CVL) was precised by the works of Baumann (1887), when he carried out geo-physical studies within the Central African sub region. This line is an alignment of oceanic and continental volcanic massifs and of orogenic plutonic complexes stretching fromthe Pagalu Island in the Atlantic Ocean in the SW to the Adamawa plateau in the NE (Gèze, 1941). It is now considered the panAfrican lineament that had permanently been reactivated from the Precambrian to the present (Moreau et al.,1987). Following the force of gravity, the resurgence of thermo-mineral water in this region mostly occurs at lineaments,fault intersections or along depressed topographic lines (Launay, 1899) where most human habitationsare concentrated (the villages of Nyos, Subum, and Bua Bua).

The pyroclastic materials constituting the walls of the caldera holding the lake's water are threatened by tectonic activities of the region. Now, if there is any toxic gas explosion from the lake or a collapse of the pyroclastic dam holding back the lake's water, two different catastrophes will certainly occur respectively. Firstly in the case of gas explosion, the gas will flow through the depressed troughs where most settlements are found. Following the general wind direction of the area, this will take NE direction to affect villages such as Subum and Bua Bua before getting to the Katsina river valley in the north to take west-ward direction and get to Nigeria some 47 km away.In the second case, due to the inclined nature of the lake under the force of gravity and the scouring activity of the lake's water thinning the pyroclastic dam, there is the threat of rupture and if this happens as it must happen one day if nothing is done, water will flow along the troughs causing floods that will register both human and property casualties right to Nigeria.

2. LANDFORMS FORMATIONAND THE CREATION OF LAKE NYOS

2.1: A highly undulating landscape

The Lake Nyos area is largely characterized by rugged relief. Here there are valleys that are flanked by steep slopes and rolling hills. When one takes a vantage position to view at the landscape in its entirety, it merely appears as a catalogue of rolling hills. This rugged relief is even more exaggerated further upstream of the Kimbi river with some of going beyond 16% of gradient[1]. Generally, this survey unit forms part of the Bamenda highlands within the Western highlands of Cameroon.

[1] This has been evaluated through contour lines on topographic maps using the formula of slope calculation
G where G stands for gradient, h for height and D for distance

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The area is dissected by streams which are all tributaries of the Katsina river system. Being part of the Cameroon Volcanic Line, it is believed that the long antichlonoriums/synchlonoriums and grabens/horsts put in place by tectonic activities contributed in shaping the landscape. Thus, it is these tectonic forces that have been responsible for the formation of folds, faults and terraces which man has valued in various ways here. The morphology of landform has been compounded by recent eruption which somehow shaped the landscape differently in function of the constituting rocks (Hawkins and Brunt, 1965).

Generally, the Lake Nyos region can topographically be considered as a vast hilly plateau. It ranges in altitude from about 650m (Kimbi systemvalley) to about 1500m further south. The area can be subdivided in to three relief elements – plateaux, elevated plains and a major river valley (Katsina river valley). According to Hawkins and Brunt, (1965); Brouwers; (1965); and Courade, (1974), the whole area is underlain by a Precambrian basement complex characterized by troughs and elevations (Fig.3). At higher altitudes, they seemed to have been covered by either quaternary alluvial deposits or by tertiary volcanic lava flows and other rocks. Such rocks are mostly of the basaltic and trachyte types. The troughs are characterized by varying altitudes: (Photo 1) low troughs in this case referring to the riverKatsina valley and high troughs referring to the valleys of the tributary rivers.

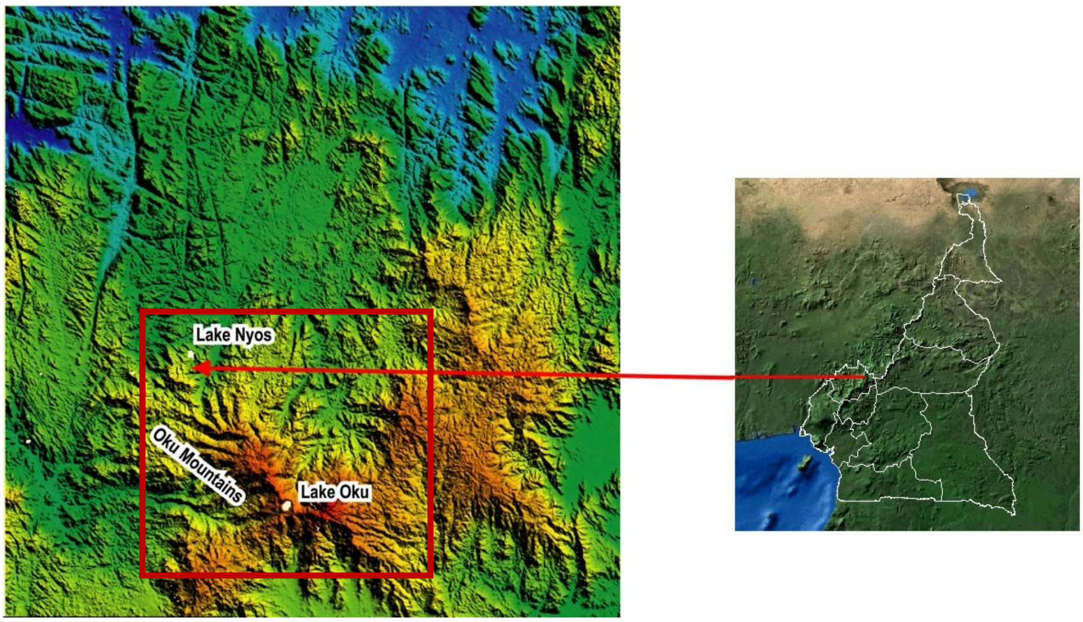

Fig: 1: location of the Lake Nyos region in Cameroon

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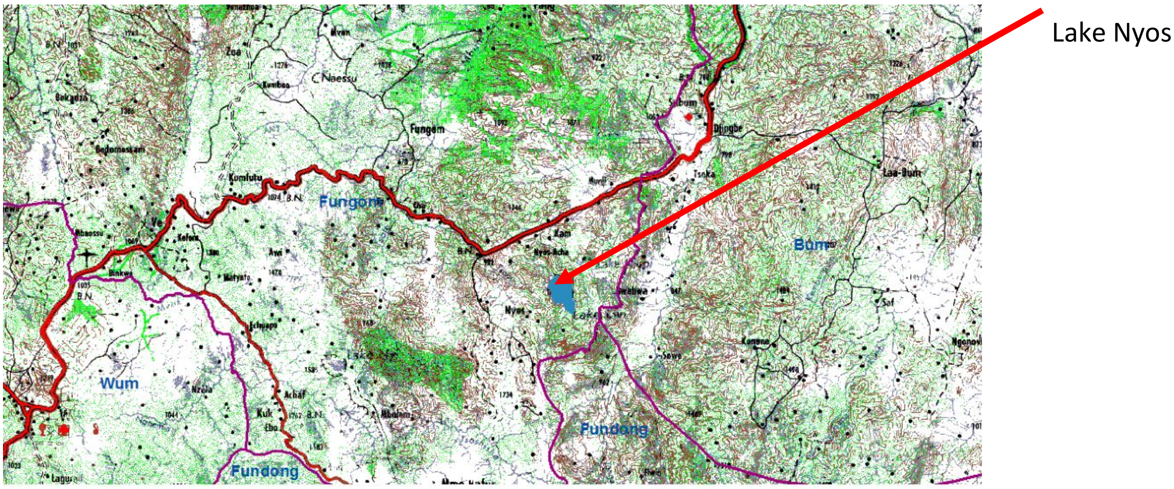


Fig. 2: Lake Nyos region

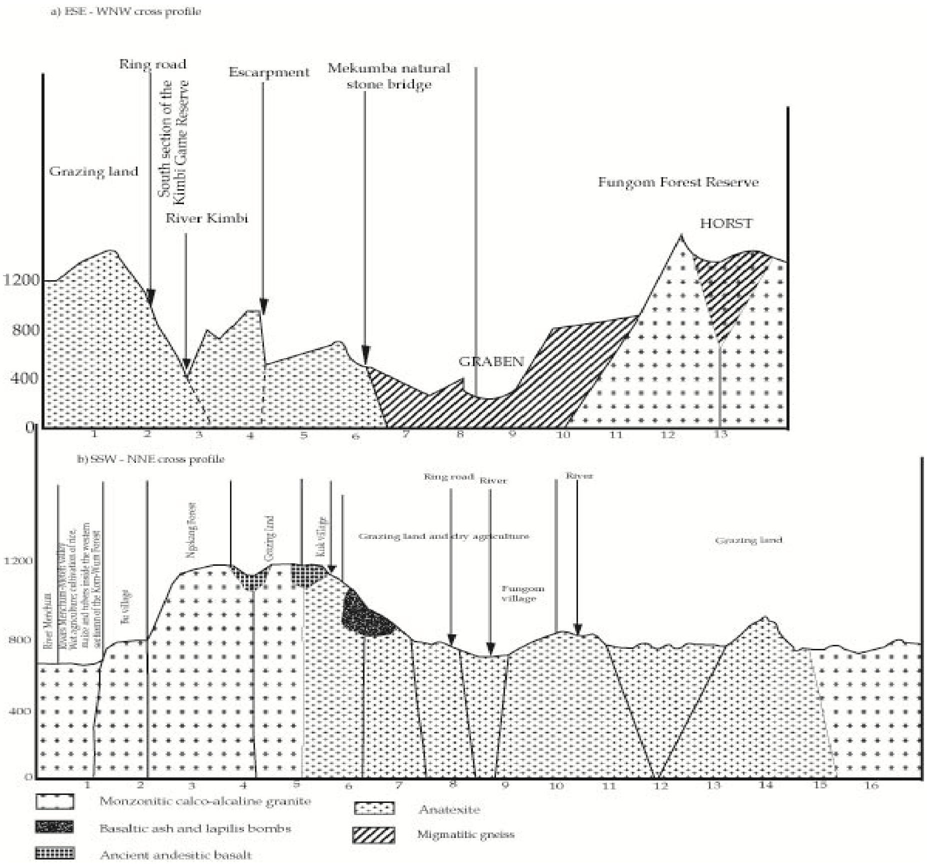


Fig.3: Topographic profiles for the Lake Nyos region
Source: Drawn from the Topographic Mapsheet of Nkambe NB 32-XVII (1/50 000) and Wum – Banyo Geological map (1/200 000)

Photo 1: Undulating landscape near BuaBua 6°13`14``N 10°21`36``E 814m (August 2013).

The Mekumba natural stone bridge across river Jonga situated somewhere in the west of the Nyos area is on a slope of about 12% gradient at 989m altitude sloping into a graben of 675m towards theFungom forestfurther in the west. This bridge is believed to have been placed by ancestors to facilitate the escape of the Munka people during the wars with the Nigerians some 150 years ago. In general, steep escarpments coupled with large stones juxtaposing or lying on each other characterise the whole of the western part of the Nyos region. These escarpments sometimes constitute sources of streams which fortify the Katsina River system; some of these escarpments towards the Fungom forest are as long as 4 to 5 km and as high as 150m. Being about 11%of gradient, they rise to above 100m.

It should be noted that this difficult terrain play a negative role for meaningful development to be realised in the region. Even when the Lake Nyos disaster erupted, the provision of social amenities was difficult as the excuse often taken was that the terrain does not favour easy movement. Thus, relief plays an active role in maintaining the region in its natural state. Beside fortifying the reverence for natural lands and endowing it with sacred powers, it has equally hindered the erection of the Kimbi Game Reserve into a national park due to accessibility problems.

2.2: Rich and Dynamic Hydrographic Network

The Lake Nyos region is drained by Rivers Jonga and Kimbi, both making up the Katsina river basin.This river system generally flows north westwards and meet with River

Menchumjust outside the Cameroon national territory at the Nigeria/Cameroon frontier where they converge and take one course under the name Katsina Ala. This river which forms part of the Niger basin flows on from here to later join river Benue which meets river Niger before emptying into the Atlantic Ocean in Nigeria. The upper course of river Katsina is river Kimbi which takes its rise from the Kilum Mountain (3011m) in Bui Division and flows northwards. Along its northwards course the river marks the eastern limit of the Kimbi Game Reserve. From the eastern edge of Kimbi forest, it turns westwards and is joined by river Tapam or Dumbo. River Tapam takes its rise from Donga Mantung division specifically from the Mbembe forest reserve and flows westwards for 15.10km before turning south to meet River Kimbi. It is from the north western edge of the Kimbi forest that river Kimbi takes the name of river Katsina which later takes a short south wards direction before finally taking a North West direction. The Western edge of the Kimbi game reserve marks the boundary between present Menchum and Boyo Division. On its North West direction, river Katsina is later joined by tributaries such as Chouto which takes the name of Mboum downstream, Imea, Yaboo and Wom. The main course of the Katsina River generally flows through the Fungom forest reserve.

Rivers within the Nyos area are faster in their flows and have narrow river valleys. Given that the hydrographic network follow main tectonic lines, farming in them constitute a risk. These risks range from volcanism, landslide and erosion to floods.

2.3 Formation of Lake Nyos (a CraterLake)

Crater Lakes partially fill a type of volcanic depression called a caldera that is formed by the collapse of solid volcano. It is believed that a dormant volcanic eruption in the Lake Nyos area took place some 7 000 years ago putting in place a volcanic cone which later blew off to create a caldera. Pyroclastic flows of pumice and ash occupied the surrounding area, including all of the river valleys that drain the region. The orientation of the drainage generally takes a north-west ward direction and flow into Nigeria. Alayer of pumice and ash spread across the region to endow the depressed spurs with volcanic soils. Erosion removed much of this material, feeding rivers that carried it far from its source, ultimately into the Katsina River system. Since the climactic eruption, there have been several less violent, smaller postcaldera eruptions within the caldera itself.

Lying at about more than 2000 m above sea level, the erupted magma was mainly of andesite. If one stands at the banks of Lake Nyos, the caldera wall displays the geologic layering of lava flows through time. As the volcanic complex evolved, so did its eruptive style. The eruptions of the last ~70,000 years were highly explosive; the eruptive magma were silica-rich (dacite and rhodacite). The eruptions of the last ~30,000 years were less explosive; the eruptive magma were low in silica. The only activity in the last 30,000 years record, prior to the caldera-forming climactic eruption of ~7,700 years ago, was limited to a small number of pre-climactic pyroclastic eruptions and ensuing lava flows of rhyodacite.

According to Hawkins and Brunt, (1968), Lake Nyos witnessedits climactic eruption about 5 500 years ago, blowing out about 270 km^3 (12 mi^3) of magma as pyroclastic materials (mostly rhyodacite pumice and fine ash)in at most a few days. The volcanic ash covered parts of the northwestern and southern sections of the region. Outcrops of these solidified igneous rock particles demonstrating this eruption can be found on the south western edge of the lake which spread to the Wum-Nkambe stretch of road. According to the report of the extent of geological formations of the North West Region produced by LABOGENIE in 2009 the volcanic ash covered a total surface area of more than 87 km^2 (at least 1 mm (fraction of an inch) thick, and no less than 11 km^2 more than 15 cm (6 in) thick.

The Nyoslandscape after the putting in place of the volcanic soils became an undulatory landscape with pockets of fertile soils here and there. Geologists have determined that the collapse of the volcanic dome to create the caldera was a relatively quick event during the eruption, occupying perhaps a few hours or days. All the valleys surrounding the volcano were partially filled with hot pyroclastic flows. The caldera was partly filled with pyroclastic materials and rock debris from its unstable walls. Subsequent to the climactic eruption, all volcanic activity has occurred within the caldera itself. Renewed volcanism built the postcaldera volcanoes of the central platform.

Following the climactic eruption, it took perhaps 250 years of rain and accompanying runoffs for the caldera to fill to its present-day lake level. The lake level is maintained by a balance between precipitation and evaporation plus seepage. By that time, the postcaldera volcanoes, nearly all of which are hidden beneath the surface of the lake, had finished their eruptions of andesite lava. Only a small rhyodacite dome was erupted later, about 1500 years ago.

Studies show that hydrothermal activities are present at the lake floor. Chemical analysis of the lake water and hydrothermal studies indicate that warm water enters the lake from the lake bottom. The water is heated by hot rock beneath the fractured caldera floor. Scientists are not certain whether any magma still remains underground but it is likely oozes out toxic gases at times undetermined.

2.4: Pedology and the corresponding vegetation

The ferralitic soils which resulted from old volcanic activities appear in pyroclastic products or fluid flow in some sections of the Nyos landscape. For example, along the river Jonga valley within the Kimbi Game Reserve, these soils appear in yellow, red or humiferous types depending on its position along the valley. These are very fertile soils which unexpectedly are the least exploited for agricultural purposes since they are mostly found in a game reserve. This soil constitute the base of forest surfaces which have largely been preserved either by the local communities in the form of sacred forest or by the State in the form of protected areas, like the Kimbi Game Reserve.

The rest of the land, grassland, shrubby savannah and ecotones witness outcrops of trachyte sometimes characterized by hard basement complexes that have no economic and cultural value to the people. The situation is further compounded by the fact it has a low water retention capacity. Their surfaces are suited for animal grazing as farming will need much effort in enriching the soil with fertilizers or animal dung for manure. Cattle rearing in the area have even surpassed the carrying capacity thus transhumance was introduced to rescue the situation. But the intricacies of this practice are that transhumance further exposes the soil and renders it unproductive. This orchestrates much leaching due to its impervious nature. The movement of cattle during the dry season when the volcanic soils on the plateaux and mountains dry out and forage supply becomes limited.

Photo 2: Lake Nyos, notice the outcrops of igneous rocks

Photo 3. Trachyte soil being dug in Nyos village to construct a house with

3. METHODS AND TECHNIQUES

The first major stage focused on lineament detection (risk zones) on the satellite images that cover the Lake Nyos region. This consisted of the search of the first drift local extremes or the passing by zero of the second drift using the ENVI software. Such an operation is generally realized by applying a high-pass filter followed and a smoothing operation (low-pass filter) in order to eliminate noise (elimination of wrong contour points). This operation of detecting contours can be realized by two separate methods: firstly through the gradient method, which uses derivation operators of the first order; and secondly the Laplacian method, which uses derivation operators of the second order (Horaud et al., 1993). These were carried out on the radar image.

3.1: Methods of applying derivation operators of the first order

These methods can generally be grouped into two. The first one is based on convolution masks of approximating gradient operator by finite difference; the second rely on sophisticated techniques, based on optimal approaches (search for an ideal contour). Techniques of the first group were applied: the gradient was calculated and local extremes of the gradient norm were extracted. An example of a signal is represented by a diagram (in one dimension) in Figures4 and 5. The contour is shown by an abrupt change of intensity.

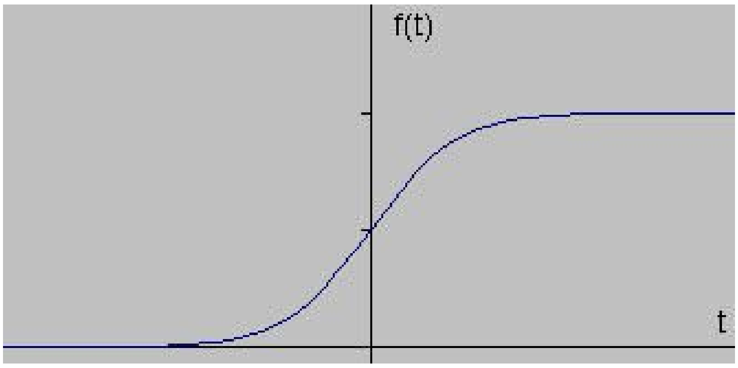


Figure 4: Graphical representation of f(t) signal.

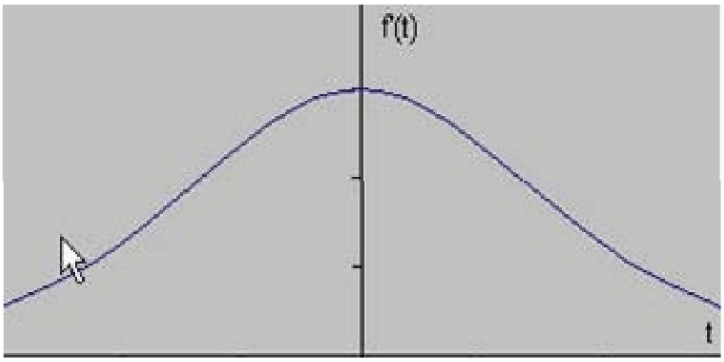


Figure 5: Graphic representation of the first drift of f(t)

The gradient of this signal is the first drift of the f(t) function (see Figure 3). In Figure 3, a local maximum clearly exists at the centre of the contour produced in the diagram in Figure 2. Based on the analysis of a single dimension, the theory can be transported to the second dimension as a calculated approximation whichcan also be obtained from the first drift in the second dimension. The gradient approach leads us to the determination of a linear filter enabling an approximation of the gradient. The gradient of a digital image is a vector that is characterized by its amplitude and its direction. Amplitude is directly linked to the quantity of local variations of the grey level.

The gradient of an image is calculated thus as follows:

$$G_x(x,y) = \frac{\delta I_f(x,y)}{\delta_x} \quad (1)$$

$$G_y(x,y) = \frac{\delta I_f(x,y)}{\delta_y} \quad (2)$$

Where: G_y = Gradient δI_f = Amplitude δ_y = Direction

At each point (x, y) of the image, we can then calculate the gradient vector.

Within the framework of this study, the max norm was chosen as it has the advantage of less computation time. In a discreet case, the approximation of a gradient is done by image convolution with specificconvolution masks. In literature there are many masks of this type amongst which we can cite:

1) **Roberts** Mask:

$$W_x = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \quad W_y = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & -1 & 0 \end{bmatrix}$$

2) **Sobel** Mask:

$$W_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad W_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

3) **Prewitt** Mask:

$$W_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \quad W_y = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

4) **Kirsh** Mask:

$$W_x = \begin{bmatrix} -3 & -3 & 5 \\ -3 & 0 & 5 \\ -3 & -3 & 5 \end{bmatrix} \quad W_y = \begin{bmatrix} -3 & -3 & 3 \\ -3 & 0 & -3 \\ 5 & 5 & 5 \end{bmatrix}$$

Where: W_x = Horizontal direction
W_y = Vertical direction
And their respective directional masks.

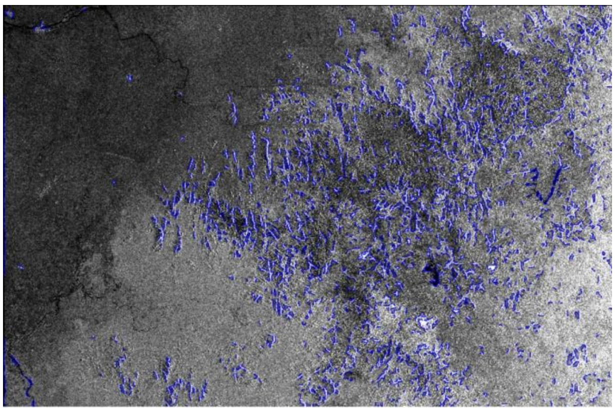
All these operations were carried out to determine the main lineaments in the region, their directions and their lengths. The operations were complimented with the use of aerial photographs, topographical maps, GPS points and field observations to determine their depths.

Using the database of the hydrographical network of Cameroon, a new table with rivers and lakes of the study area was created in MapInfo. This was superimposed with the geo-referenced radar image used above to create another table that was used to determine the lineaments. 12 aerial photographs obtained in 1964 by UAG mission (NB32 XVI-XVII) were equally geo-referenced (series No. 524 - 529 line 1; and 586 – 591 line 2) and the layer of lakes alongside wells were created and also imported into the MapInfo tables. The location points of the wells were obtained thanks to GPS measurements taken during fieldwork. The resulting map (Fig.8) from the above combination shows a juxtaposition of fault lines, lakes and springs.

Since the rocks are generally of granitic nature in a region characterized by tensional forces and undulations, the superimposition of the hydrographical network on a three-dimensional surface clearly shows the general inclination of the region.

3.2: Detection of lineaments

With the use of ENVI software on the JERS radar image (Fig. 6), the High Pass Lapacian method was applied to determine lineament orientations. This actually based on the derivation method of the first order and signal method with four main directions (0°,45°,90° and 135°)(Fig.7):High-pass and Laplacian filters on a radar image (a, b) and on aerial photographs (c, d).



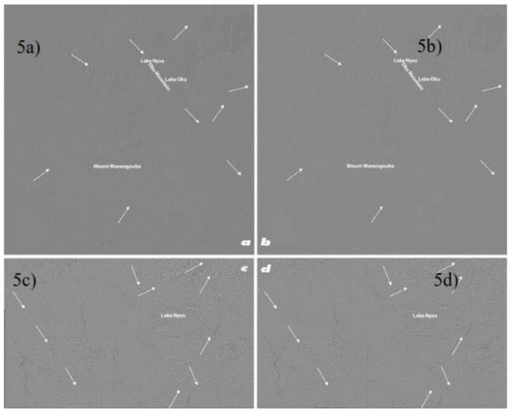


Fig.6: Ddetection with 1st order derivation Fig.7: Detection with signal method

The geo-referenced radar image was then imported into a GIS software (MapInfo) where the interpreted lineaments were drawn to determine their distances

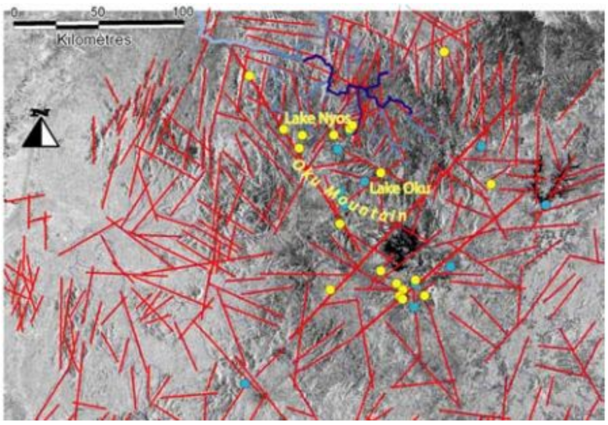


Fig. 8: Hydrographic network superimposed on radar image

4. RESULTS

4.1: Risk zones in the Nyos region

As already noted above, Lake Nyos and its environs poses as a risk zone. These risks of eminent gas explosion and/or floods do not only threaten this part of Cameroon but also settlements in the eastern parts of Nigeria in localities such as Achilo in the south of Takum, the nearest administrative headquarters in this part of Nigeria. Following the treatment of the remotely sensed data, it could be observed that most of the fractured zones are occupied with aquifers. The detected lineaments show that the main directions lie parallel to the most active volcanic line in Cameroon today. Most of the springs identified are located at the intersection points of fault lines. It is these springs that later constitute the main rivers in the region which in general take a SE-NW direction flowing into Nigeria to form part of the Niger basin. Out of the 44 volcanic lakes in Cameroon, more than a half, that is, 23, are found in this volcanic province, while the lake Nyos region alone has 13 such lakes. This confirms what Tchindjang (1996) estimated by stating that this region falls within one of the most active fault lines if not the most active fault in Cameroon (Fig. 7).

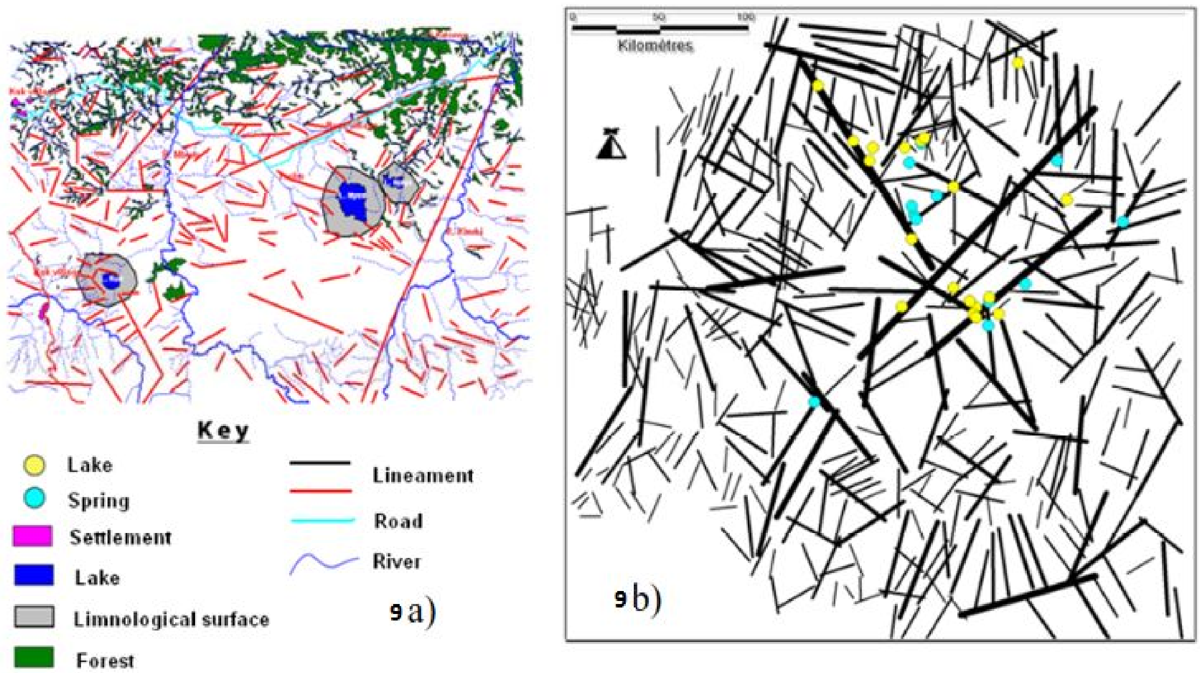
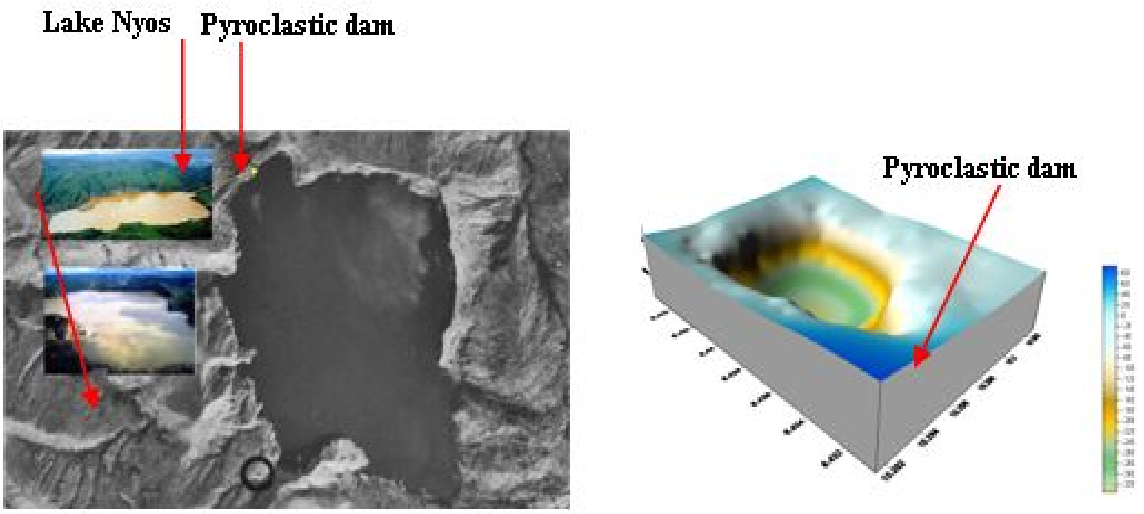


Fig 9: Thematic analysis of lineaments based a) on aerial photographs and b) on radar images

According to the treatment and the interpretation of the raster data, figure 9a shows the main directions of the lineaments within the Lake Nyos region on a mosaic of aerial photographs. Those indicated in black extend beyond 1 km in length while those in red are less than 1 km. On the other hand, Figure 9b covers a much wider surface on a radar image and represents the thematic analysis of lineaments. The thick lines represent lineaments more than 10 km long while the thin ones are below 10 km long. Thus the main risk zones in the Nyos region are the river valleys of Jonga, Kimbi and Katsina Ala where we have settlements such Bua, Kimbi village, Nyos village, Subum and Tcha. Further downstream of these fault lines are Kpep; Furu Awa, Munkep, Akum, Lubu, etc in Furu Awa Sub Division of Menchum Division and farmlands as the inhabitants in this zones spend most of their time on the farms.

4.2 An assessment of the risks

Assessing the extent of the risk depended upon the proper use of the remotely sensed data. The distribution of lineaments and the evolution of the vegetation were analysed. Field observations revealed that fractures exist on the pyroclastic dam (Fig.10a) of the lake since 2001. These are accompanied by widening potholes dug by the process of erosion. Thus, the main risk is linked to the pyroclastic dam that surrounds the lake presented in Fig. 10.



a) Lake Nyos with indications of the pyroclastic dam

b) Digital Elevation Model of Lake Nyos

Fig.10: Aerial photograph of Lake Nyos and its digital elevation model

Source: Tchindjang et al., 2008

In case of an earthquake, this dam is likely to break off releasing about 3 billion $m^3$of the lake's water alongthe valleys which will flow right to Nigeria. It should be noted that these valleys are oriented by the fault lines and they principally form the River Katsina basin. Apart from straightness, the angle of bifurcation of the main river (Katsina and its tributaries) is an indication that drainage lines follow fractures.

Another risk is linked to an increasing number of exposed people to risk in this region. The return of thelocal population, who for the past 20 years had been living in Bua Bua and other resettled localities, is feared most. This return, it is expected, will certainly orchestrate underground water change, deforestation and the re-conquest of savannah in the present forested zones. Besides, since one cannot predict the occurrence of natural hazards, the returning population will still be exposed to the same danger as of 1986. This means that more deaths will be registered in case of another explosion, which is imminent as many studies have proventhat the fault lines are still very active. The degasification process which is still in process, points to this fact.It should also be noted that the gas emitted during the 1986 explosion mostly flew across fault lines and the population settled along these lines were the most affected.

5. DISCUSSION

The lake Nyos region which falls within the Cameroonian dorsal remains the most active fault line in Cameroon. This fault line stretches from the Atlantic Ocean to the Adamawa plateau. To this effect therefore, the region needs to be constantly surveyed as one cannot predict which volcanic eruption can take place at any given moment in time. Apart from the tectonic activities, the frequency of landslides, especially during the rainy season, constitutes another risk to the population, and it is rather this factor that was taken into consideration for the resettlement of the survivors. Thus the Bua Bua site, a relatively flat area to the east of Lake Nyos where the survivors of the lake Nyos gas explosion were resettled, cannot be considered to be final. This is due to the fact that from mid-June to October, the general wind circulation in this region is West-East. As was the case in 1986, any explosion from the lake will carry the gas to the East following principally the fault lines. This factor was actually not taken into consideration during the resettlement process. This can be proven by the fact that the accompanying measures were never implemented. Multi-date satellite images are well adapted to diachronic approach which is of prime importance in determining the distribution of lineaments and the management of risks. Therefore the powers that be have to rethink the resettlement process in light of remote sensing data.

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Given that the thickness of the dam is 20 m, it cannot be detected through images of low resolution (one pixel being 25 m). Thus, from field work and the generation of a DEM, it became possible to obtain viable and acceptable information on the dam's fragility. It is observed that if the dam continues to thin down due to the scrubbing action of the lake's water generating potholes, the natural dam might break in the near future. In case of collapse of the dam (due to earthquake or volcanic eruption), given the quantity of water contained in the lake, four categories of risk zones were identified: high, moderate, low and very low risk zones. Most of the population is settled in the high risk zones (valleys or tectonic corridors). After the gas explosion in 1986, the resettlement concentrated the survivors in those zones. The generated DEM with a topographical map a 1:50,000 (Fig. 9) shows that the landscape is highly undulating and the hydrographic network is dense and sinuous. Watercourses directly follow the tectonic orientation.

The map of exposure to floods drawn from this DEM will certainly provide an important basis for decision-making (Fig. 11).

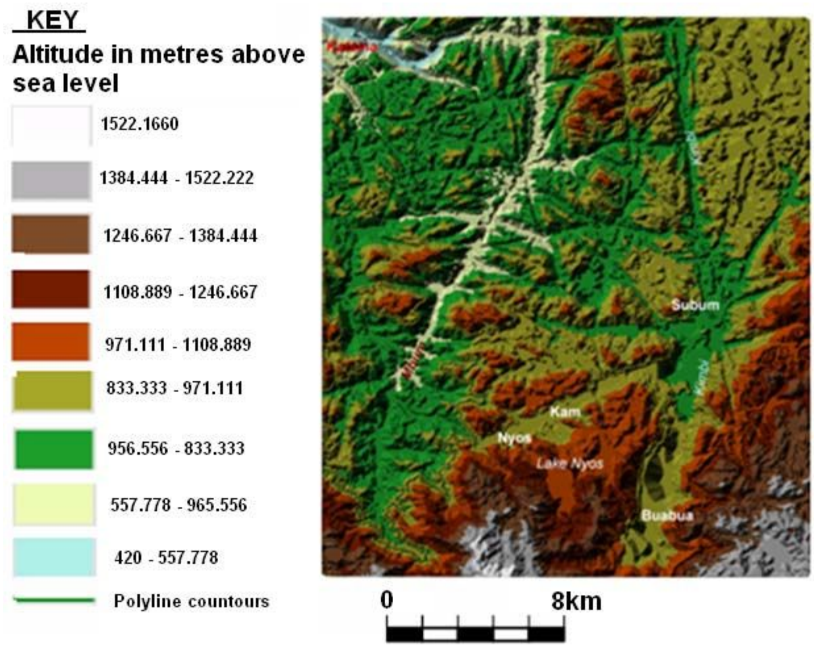

Fig. 11: DEM for the lake Nyos region

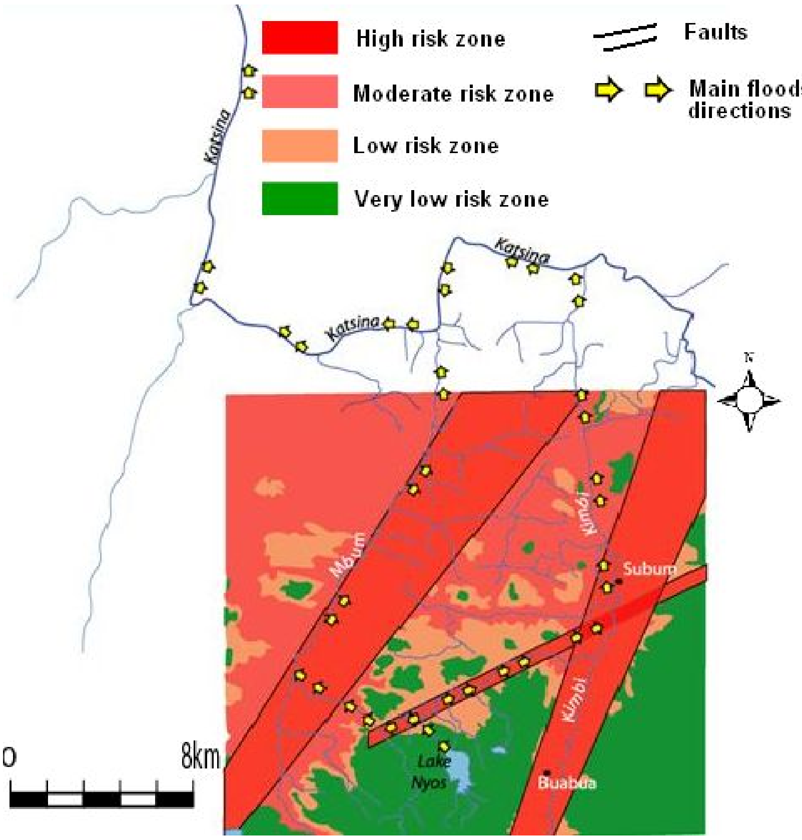

Fig. 12: Determining zones exposed to floods

6. CONCLUSION

The Lake Nyos region, which lies along the Cameroon Volcanic Line, is subjected to two major risks which are devastating both to the environment and to human lives. To assess these risks, different databases were used - satellite images, aerial photographs, hydrographic network of Cameroon - and complimented with ground-based measurements. Most important use of the radar satellite image was the detection of lineaments using derivative methods of the first and second orders while the optical satellite image served in determining vegetation change in the region. The geo-referenced aerial photographs were useful for zooming-in on the area to specify and characterize the lineaments. Inferences cannot be drawn from these operations alone. It is for this reason that these had to be complimented with ground based measurements, in the form of photographs and GPS points. The results then showed that Lake Nyos area poses as a potential zone at risk, i.e. the resettled sites of the local population created after the gas explosion in 1986 are not safe. The surviving population returned to their original site: in addition to their exposure to risk, the environment will be made more fragile. Lastly, a rupture of the pyroclastic dam holding the lake's water may cause floods that could threaten about 10,000 people along the fractured lines both in Cameroon and in Nigeria.

Much attention is therefore needed in this region to mitigate if not avert the occurrence of any disaster.

7. REFERENCES

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