Remote sensing for developing countries: Landsat data and Gis

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Abstract
The efficient management of big cities requires the knowledge and the integration of the several data necessary to describe the huge number of variables that govern the urban environment evolution. In developing countries, where the resources are scarce or in-homogeneously distributed, the problem of acquiring reliable data is amplified by the unfavourable local conditions and the integration of data of different nature can be extremely complicated without appropriate instruments. In this paper we present a project devoted to develop cost-effective Geographycal Information System solutions for the integration of data (remotely sensed, social, economical, and so on). Both the organization and the technical issues of the project are presented. The project validity has been tested in the frame of a case study implemented in the city of Goma, Democratic Republic of Congo (RDC). The project was born by the collaboration with local institutions (the Don Bosco Centre and the United Nations mission in Congo (MONUC)). These organizations needed a GIS supported decision to sort out two specific problems: the location where to build up refugee camps in case of the Nyiragongo volcano eruption, and the places where to build permanent houses for local people. *In situ* data have been retrieved thanks to the cooperation with international and local organization and efficiently organized. In addition, value added maps have been developed, providing efficient solutions for the proposed problems.

Riassunto

Introduction

Urban settlements are complex environments, in continuous evolution, where most of the world population lives. The organization and the distribution of the available resources in big cities is an intriguing issue, which requires continuous and large scale monitoring on geophysical, economical, social and political variables. In developing countries most of the cities were developed without a rationale and the life conditions are often intolerable. In the poorest urban settlements it is difficult to have a reliable idea of the dimension of the existing problems, and local authorities are unable to get the minimal data necessary to control and efficiently drive the urban expansion. The access to the information is often limited by unsafe working conditions; in addition, traditional methods require acquisition time much higher than the typical changing rates of the studied area.

Despite the existing remote sensing instruments are already able to extract useful information in this scenario, so far scarce interest has been focused by the scientific community toward specific applications for developing countries. In this paper we present a project whose goal is the efficient exploiting of existing remote sensing sensors data and Geographical Information System (GIS) facilities in order to provide numerical instruments to support the urban monitoring and organization processes.

The implementation of such a project poses intriguing challenges for the solution of both technical and social issues. In fact, beside the typical technical problems related with integration of data coming from different sources and the efficient extraction of information from them, the definition of the GIS classification criteria has to obey to social and ethic principles, often neglected in traditional projects.

Up to now, remote sensing technology has been scarcely exploited in developing countries because of its high costs. In the presented project the acquisition and the integration of data are thought with the aim of reducing the costs, also thanks to the use of dedicated Open Source software.

The presented project has been implemented in a case study, in the city of Goma, Democratic Republic of Congo (RDC). The case study is particularly significant, because the presence of the Nyragongo volcano and the unstable political situation add further difficulties in the phase of making decision for the city organization.

In **Section 2** we present the general project rationale, introducing the basic concepts that drive the organization and the time scheduling. The implementation of such a project is strongly influenced by the local conditions, hence in **Sections 3 and 4** we focus our attention on the Goma case study. In particular, **Section 3** is devoted to present the preliminary studies necessary to prepare the operative phase and to define the project objectives.

The collaboration with local actors (mainly ONU and Don Bosco centre) allowed to define two test problems related to the building of refugees camps and new safe districts in the Goma area. In **Section 4** the solutions proposed by the joint work of Ingegneria Senza Frontiere Napoli and the University of Napoli is presented. **Section 5** is devoted to the final conclusions.

Remote sensing for developing countries

Project organization

The efficient implementation of an operative project requires a precise schedule of the actions to be performed. In this Section we present a general framework whose rationale is intended to be a guide for specific implementation. In particular, the operative work has been structured in seven steps, here defined as Macro Work Packages (Wp).

- Wp1: Definition of users' requirements
- Wp2: Existent background survey

– Wp3: Study of technical specifics
– Wp4: Study of resources availability
– Wp5: Data elaboration
– Wp6: Training
– Wp7: Education

The first part of the project (Wp1 and Wp2) involves the preliminary study of the local situation, *i.e.* a social analysis on people actual needs. This is a crucial step in this project because it affects the fullfillment of needs felt by the local population. In addition, in this phase, it is necessary to identify typical problems of developing countries which can be studied with remote sensing techniques. As for the urban areas, we have detected four main classes of topics:

–Water: lack of sewers and of drinkable water.
– Enormous demographic flows, runaway development of Bidonvilles, favelas and so on.
– Air, land and water pollution.
– Rubbish logistic and management.
– Management of emergencies.

In the present work we focuse our attention mainly on ready and effective urban pianification in case of emergencies and on the importance of water management in this kind of situations.
Once the object of the work has been defined, the appropriate remote sensing instruments for the identified purposes have to be chosen (Wp3, Wp4). The data useful for the project success have to be defined and the processing algorithms designed. In addition, the availability of resources (funds, hardware, software, data and so on) has to be tested, in order to dimension the project on the actual possibilities.
Then, the proposed solutions can be implemented according to the goals and the constraints identified in the previous project steps (Wp5). In this phase, the remote sensing data are interpreted, geo-coded and integrated with data of any other type. Dedicated software and solutions are implemented and the required information are retrieved from the data, in order to provide a solution to the posed problem.
The last part of the project (Wp6 and Wp7) consists in the knowledge transfer phase. In fact, it is crucial that all the developed applications could be repeated by local subjects. Therefore, the know-how of the proposing group has to be shared, mainly with local operators.
The developing countries cities are very different with respect to ours, so, in order to test the validity of the proposed framework, in the following the attention is posed on the implementation of the project in the city of Goma in the Republic Democratic of Congo. The implementation of the described steps is treated with details in the next sections.

The Goma case study: preliminary studies and data collection

Users' requirements

In this Section we present a case study, developed to give an answer to the requests of Ngangi Don Bosco Center, in the city of Goma, in the Nord Kivu region of RDC. The project has been implemented in collaboration with the ONU mission in Congo (MONUC) and the Volcanologic Observatory of Goma (OVG).
According to the project schedule of **Section 2**, it is crucial a previous analysis of the Nord Kivu region specific problems, in order to define the "users' requirements".
Goma is a city with nearly 400.000 inhabitants, which presents most of the typical problems of urban areas in developing countries (lack of infrastructure, of water networks, of sewers, overpopulation and so on). Since 1998, two and a half millions of people have died in the Eastern RCD from infectious diseases and malnutrition.

The city is located under the active volcano Nyragongo, which frequently destroys part of the urban area. The last Nyragongo eruption, in January 2002, burned out the city centre, making the need to find appropriate reactions to the next volcanic events arise.
Furthermore, the city is situated in an area affected by an unsafe political context. The political situation determines significant displacements of persons in the Goma area. The examined region is afflicted by a humanitarian crisis and a chronic complex emergency due to the presence of armies and armed groups of at least six countries [Baxter et al. 2002].
An analysis of the needs felt by the population, developed in conjunction with the Don Bosco center and the MONUC office for the coordination of humanitarian affairs (OCHA), which supplied us some maps, demographic data and so on, led us to focus the project on two main goals: the identification of areas with low volcanic risk, where it is possible to build permanent districts for local people and the planning of a quick strategy to locate sites where to build refugees camps.

Technical specifics and resource availability
In the context presented in **Section 2**, the use of remote sensing technology can be crucial in order to retrieve useful information for the project objectives. Anyway, as usual in developing countries, the available resources are scarce, sparse and unreliable. In this Section we present how we collected the available data and how we re-organized them in order to have a useful database for the achievement of our tasks.
The available raw data are listed in the following:
– UN - GIS UNIT non-georeferenced maps were provided by OCHA on the Goma city centre topography and the Nord Kivu region; demography, childish mortality rate, environment and health punctual informations were also provided.
– Old non-georeferenced topographic map of Goma, made during Belgian colonialism was provided by the "Don Bosco Ngangi" center.
– Landsat ETM+ images of Nord Kivu region, acquired from the Michigan State University's Center for Global Change & Earth Observations. These data have been realized by the U.S. Geological Survey (USGS) and consist of 7 data files organized according to the Hierarchical Data Format (HDF); the sensor is the Enhanced Thematic Mapper Plus (ETM+) and the area of interest is located in between three different countries: D.R. of Congo, Rwanda e Uganda, between 1° and 1°50" south, and between 29° and 30° est. This set of data has already passed through the image restoration phase. The geodetic-cartographic system used in georeferencing our images is WGS 84 – UTM (zone 35).

Further information on local infrastructures and first aid centers were acquired via *in situ* studies in collaboration with the Ngangi center personnel and volunteers and via contacts with local authorities.
Available data could not provide useful informations if not appropriately integrated and processed. Therefore, the first step of the technical part of the project was focused on the organization of available data. In particular, we synthesized the most relevant Goma parameters in three maps, presented in the following.
We georeferenced and merged the images. We georeferenced the available data using the open-source software GRASS-GIS, commonly referred to as GRASS, a GIS used for geospatial data management and analysis, image processing, graphics/maps production, spatial modeling and visualization. In Figure 1 we present the result of our analysis concerning the areas of Goma affected by the lava flows of the Nyragongo eruption in January 2002. It is shown that the city center was strongly affected and some districts completely destroyed. One of the two main lava flows shown in the figure crossed the city and reached lake Kivu. This lava flow destroyed the administrative centre of the city, where the most

Figure 1 - Recent lava flows effect in the Goma center.

important buildings of city authorities were located. A second flow (in the center of Figure 1) destroyed two popular districts of the city, principally made up of wooden shacks. In the map the distribution of humanitarian offices and of health centers (Centres de santè) are also shown.

In Figure 2 the water supply network as acquired by in situ surveys is shown. The dotted blue lines represent the drinkable water supply, the yellow ones identify the pipes destroyed by the 2002 Nyragongo eruption. The water distribution for the Goma population is not uniform. In the map in Figure 2, the darker the colour of the area, the more regular is the water supply. Note that most of the water is taken from the lake (the two uplifting points in the North-East area of the map are shown): such a procedure poses safety warnings because water contains volcanic minerals and can be often contaminated by sludge.

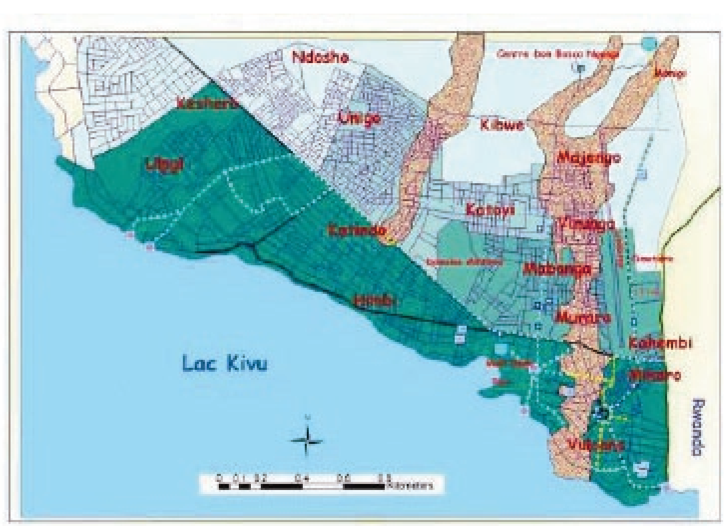

Figure 2 - Water supply in the city of Goma.

Figure 3 - Power supply in the city of Goma.

In Figure 3 the electrical distribution service is presented. The darker the area in the map, the more regular the electricity distribution service. Note that the richest districts (located in the North-East area of Goma) and the airport area (the straight line near the Rwanda border) are regularly reached by the water and electricity supplies. Conversely, the poorest zones of the city (North of Goma) are actually not reached by water and electrical supplies.
The produced maps summarize and make easily interpretable the pre-project information. In the following Section we present the GIS applications developed to give an answer to the problems identified by our local partners.

The Goma case study: gis applications

In this Section we present the solution we provided to face the problems identified in **Section 2.**

Identification of safe areas for new districts
Why to analyse the lava?

In order to define the criteria to classify the most dangerous districts, a preliminary study on the lava flow characteristics is required.
It is possible to identify two main Nyragongo's lava types: a fast and fluid one, known in literature as "pahoehoe", and a slow an rough one, known in literature as "AA".
The first is very dangerous for the people, because it is very fast, up to 40 Km/h. However, the "pahoehoe" lavas are not dangerous for the buildings because the pressure applied on the constructions is not very high. Conversely, the "AA" lavas are destructive for every type of building. Therefore, the knowledge of the past eruption lava composition is crucial to foresee its behaviour in case of new eruptive phenomena.
In order to do it, we made an in situ survey with the volcanologists of OVG, picking up several samples of lava. But, it is impossible to reach some sites of the Nyragongo volcano because of the insecurity of the zone. Hence, remote sensing instruments are suitable to retrieve crucial informations.
The Landsat data described in **Section 2** are extremely useful for lava classification purposes. In particular, we studied the lava flows using four different techniques:

- Study of LWIR band (8-12 µm), [Harris et al. 2002; Wright et al. 2003].

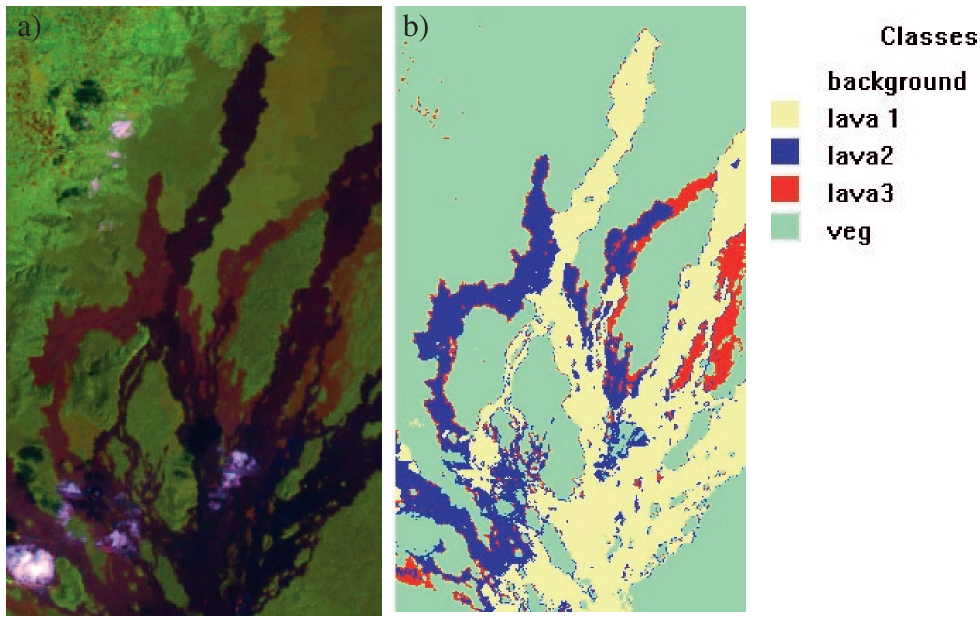

Figure 4 - a) False colour Landsat image (bands 5-4-1); b) Results of the Multi-Spec classification.

– Image classification on singles bands with MultiSpec software.
– Image classification on three-bands images with MultiSpec software, [Serpico 2004].
– Index method.

We discovered that the most effective way to study the overlapped lava flows is the classification on three-bands images. With this approach we can detect and separate flows coming from up to three different eruptions. As an example, we present the supervised classification of these three different lava flows in the northern region of the Nyragongo volcano.

In Figure 4a we show the false colour image obtained by the merging of the bands 5-4-1 of the Landsat data. The obtained image has been classified via a supervised maximum likelihood criterion and the result is presented in Figure 4b. In the classified image we can distinguish three overlapped flows marked in three different colours [Serpico 2004]. The users' accuracy of the classification is adequate for the first lava type (87.7%); conversely, being the other two lava flows covered with vegetation, we obtained a good classification accuracy (96.5% for lava2 and 100% for lava3), but a poor users' classification accuracy (43.2% for lava2 and 42% for lava3) [Arnoff 1982].

With the same approach we can study the two lava streams which destroyed Goma city centre. In the classification of the region a further "urban" class has been added to show Goma buildings. The city is made essentially of wooden slums laid on the lava of volcano Nyragongo, and so it's really difficult to distinguish the flows from the urban buildings. In Figure 5 is possible to see secondary flows in the north of the city.

Goma city volcanic risk map

As usual in developing countries, available data are scarce and a complete risk map requires financial funding. Anyway, in this paragraph, we show that important information can be extracted by few data, via efficient GIS techniques. We generated a map to individuate the best area where to build houses for the refugees of the January 2002 eruption. The

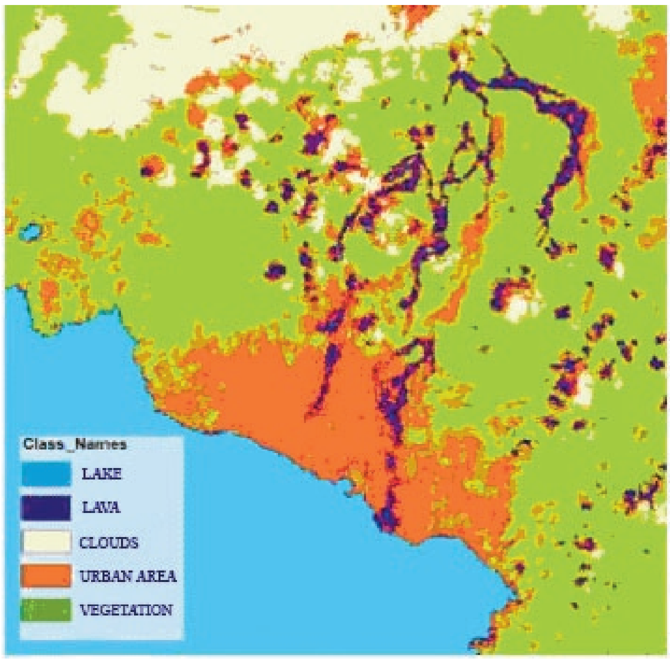

Figure 5 - Lava classification in the Goma area.

construction of the buildings is financiated by the "Don Bosco Ngangi" centre and intends to build up 200 houses with 5m x 10m base. In order to locate the most suitable place where to build up this district, we have selected four criteria (Tab.1).
The Nyragongo lava flows in the last 50 years came out from several fractures located between lake Kivu and Nyragongo's top. In Figure 6 we present a geological map provided by the OVG. During the last eruption the lava that destroyed most of the city centre spurt out from two main fractures, closer than 3 km to the city borders and identified in Figure 7 by the dashed red lines.
Using the GIS-GRASS, we identified the city areas where all the proposed criteria were fulfilled. In Figure 7 we present an easily readable map with the result of our analysis. The red areas represent those areas in which the district for the refugees can be built with a low volcanic risk, sufficient water supply and so on.

Table 1 - GIS buffering criteria.

Feature	Criterion	Motivation
Volcanic fractures	2 km afar	Future eruptions prevention
Roads	Less than 400m afar	Communication ways accessibility
Water pipes	Less than 400m afar	Drinkable water accessibility
Lake	More than 350 m afar	Water contamination and epidemics prevention

Identification of suitable areas for refugees camps

As stated in **Section 2**, it was also required to identify the best area where to build up an emergency camp, in case of a new volcano eruption or civil war.

The zone under study is one of the most vegetated areas in the world and is characterized by the presence of a large National Park. In this context it is crucial to monitor the vegetation around the urban settlements also because it is forbidden to build up in the National Park area.

The proposed study has been carried out also using a vegetation index, the GVI (Green Vegetation Index) [Crist et al. 1984; Crist et al. 1984] defined as follow:

$$GVI = -(0.2848xband1) - (0.2435xband2) - (0.5436xband3) + (0.7243xband4) + (0.0840xband5) - (0.1800xband7)$$

Using this index we were able to distinguish very clearly on the available images the borders of the National Park of Virunga.

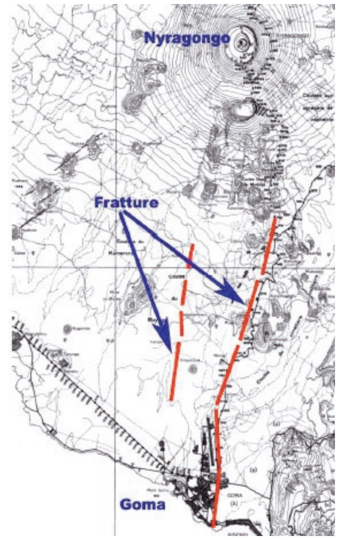

Figure 6 - OVG geological map.

Note that we choose the GVI also because GRASS calculates automatically indexes generated by Tasseled Cap Transformation of Landsat images.

In order to identify the areas in where it is possible to build the refugees camps, we stated the following criteria (Tab.2).

In addition, we must obviously consider that we have to build the camps far away (at least 2 km) from the volcano fractures.

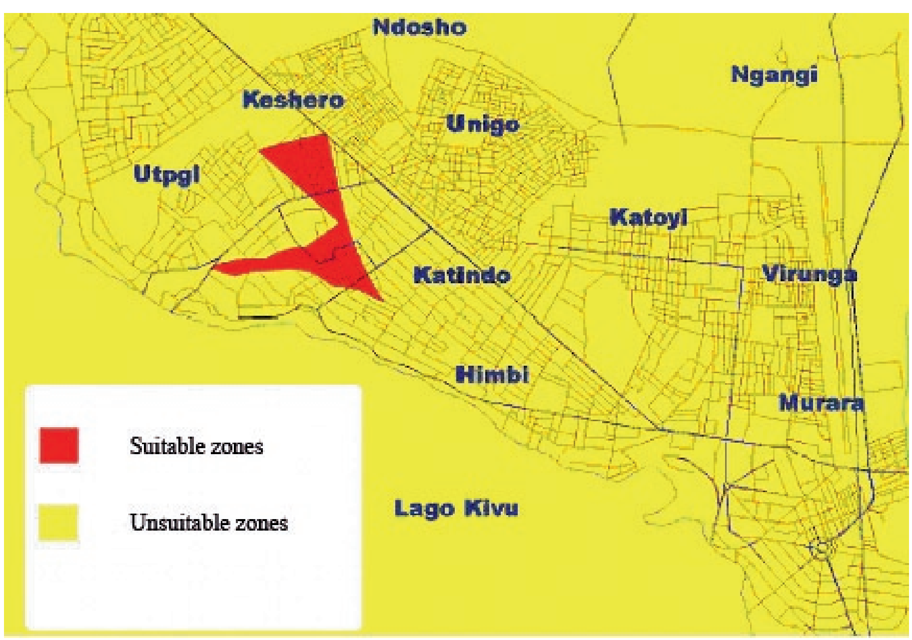

Figure 7 - Identification of areas suitable for new districts.

Table 2 - GIS buffering criteria.

Feature	Criterion	Motivation
Virunga National Park	1 km afar	Habitat and rainforest protection
Roads	Less than 500 m afar	Communication ways accessibility
City boarders	More than 1 km afar	Public order and health management
Lake	More than 400 m afar	Water contamination and epidemics prevention

It's easy enough to achieve the last three criteria using GRASS on the maps we obtained and elaborated previously. On the other hand the first criterion was fulfilled working on the GVI elaborated image of the zone: from the GVI map we created a vectorial map containing the borders of Virunga National Park and then from this second map we obtained the required criterion of distance from these borders.
In this way we obtained the image shown in Figure 8 where the areas of interest are marked in green. Now we have to consider the distance from Rift Valley: as we have seen in the lava study one of the two resulting zones is just near a crack. So we have to consider only the green zone on the far left of our image.

Conclusions

In this paper an innovative project for the use of remote sensing data and GIS applications in developing countries has been presented. The project organization has been shown and a significant test case implemented. Efficient solutions for specific problems born by local organizations requirements have been proposed.

Acknowledgments

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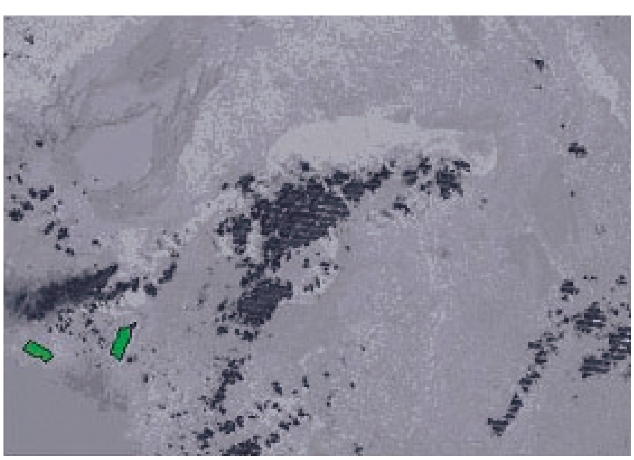

Figure 8 - Identification of areas suitable for refugee camps.

References

Baxter P.J., Ancia A. (2002) - *Human Health and vulnerability in Nyragongo Volcano crisis in D.R. Congo*. WHO, University of Cambridge.

Serpico S.B. (2004) - *Classificazione statistica di immagini telerilevate del territorio*. Dip.Ing.Elettronica, Università di Genova.

Harris A.J.L., Flynn L.P., Matìas O., Rose W.I. (2002) - *The thermal stealth flows of Santiaguito dome, Guatemala*. Geological Society of America Bulletin.

Wright R., Flynn L.P. (2003) - *On the retrieval of lava-flow surface temperatures from infrared sat. data*. Geological Society of America.

Flynn L.P., Wright R., Donegan S. (2002) -*EO-1 Observations of Volcanoes.* EO-1 SVT Meeting.

Arnoff S. (1982) - *Classification accuracy: a user approach.* Photogrammetric Engineering and Remote Sensing. 48:1299-1307.

Crist E.P., Eric P., Cicone R.C. (1984) - *A physically-based transformation of thematic mapper data.* The TM tasseled cap. IEEE Transactions on Geoscience and Remote Sensing 22(3):256-263.

Crist E.P., Cicone R.C. (1984) - *Application of the Tasseled Cap Concept to Simulated Thematic Mapper Data*. Photgrammetric Engieneering and Remote Sensing, vol.52, no.3, pp.343-352.

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