Identifying potential landslide location using Unmanned Aerial Vehicles (UAVs)

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ABSTRACT

The impact of landslides is determined by the previous state of vulnerability and susceptibility present in a community. Vulnerability is related to physical aspects and susceptibility is defined as the propensity or tendency of an area to be affected by the occurrence of a given hazard. Knowledge of geography allows us to characterize and measure some of these factors. For example, in landslides called huaicos in Peru, these are related to the existence of a slope and soil type of the hills favorable to the loosening of land masses, as well as the increase in rainfall and the presence of streams. The use of UAVs (Unmanned Aerial Vehicles, commonly called drones) for the identification of susceptibility zones is presented in this paper. The result is positive for using the georeferenced data to identify potential landslide flow using as unique criterion surface slopes.

Keywords

Susceptibility mapping, disaster prevention, landslides, drones.

INTRODUCTION

Within the mitigation stage, decisions are made taking a strategic perspective to reduce the potential impacts of a disaster or to avoid it; thus, risk analysis is normally part of this stage (Altay and Green III, 2006; Leiras et al., 2014). Vulnerability and susceptibility maps become enormously important, because it allows knowing in advance, where the most exposed and dangerous areas are located. These tools support elaborate qualitative and quantitative information, such as: forecast impacts post disasters, evaluate options of preventive intervention, risk control planning (using elimination, isolation or reduction strategies), guide where the investment of infrastructure to mitigate vulnerability must be made, determine the sociodemographic characteristics of the threatened territory (MINEDU, 2015). Nowadays, vulnerability maps are widely used by various public organizations, non-governmental organizations and companies to track, evaluate and manage the different risks to which they are exposed.

Risk mapping is the presentation of the results of risk assessment on a map, showing the levels of expected losses which can be anticipated in specific areas, during a period, because of disaster hazards. The risk is defined as the combination of the probability of an event and its negative consequences (UNISDR, 2009). The latter is related to expected losses such as fatalities, persons injured, damage to property, and disruption to economic activity, etc. caused by a hazard (Coburn et al., 1994). Risk assessments include: a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability including the physical social, health, economic and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities in respect to likely risk scenarios. This series of activities is sometimes known as a risk analysis process (UNISDR, 2009). Zhao and Chen (2015) present a methodology for the risk assessment (see Figure 1). The process of risk assessment is based in a mesh spatial representation, where an entire region is divided into a few fine spatial meshes with a specific risk value. The procedure considers both hazard sources and risk targets (hospitals, schools and commercial centers, etc.). For each mesh, the risk level is calculated considering the severity and vulnerability level. The severity measures the intensity and frequency of the hazard. The vulnerability measures social indicators, such as population and its structure, the accessibility of emergency resources, etc. Mapping and disaster assessment can improve the provision of timely and accurate support for activities such as evacuation, sheltering and distribution (Rodríguez-Espíndola et al., 2016).

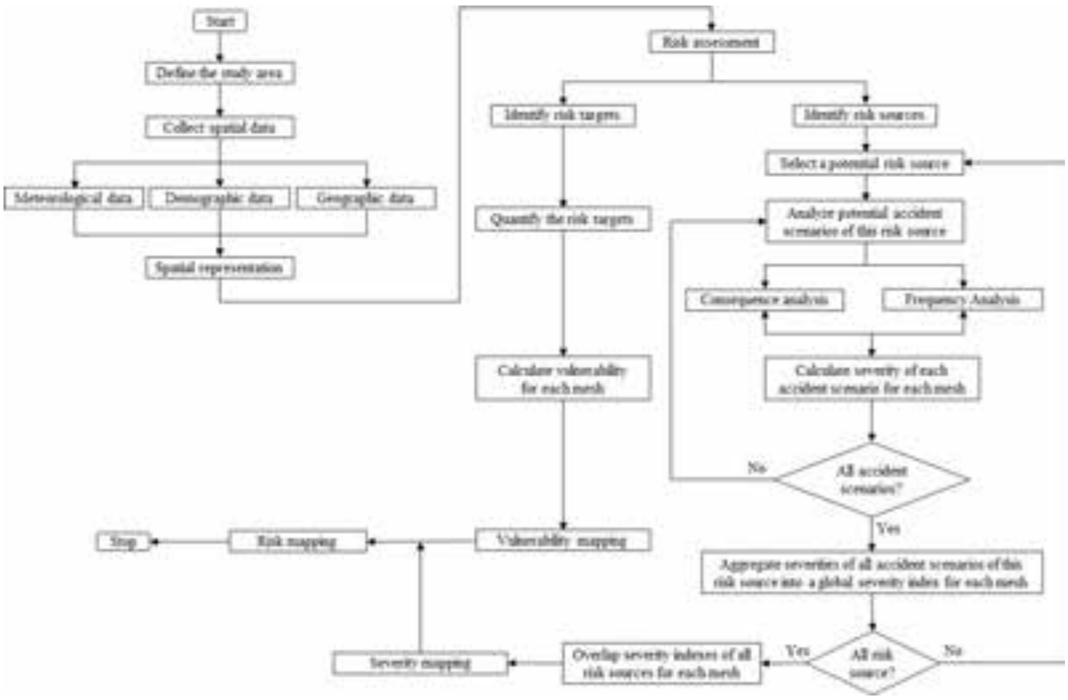

Figure 1. Flowchart of risk assessment and mapping (Zhao & Chen, 2015)

According to Lewis (2004) "vulnerability" is related to physical aspects and "susceptibility" to a previous weakness of capacity to manage it. In many cases, it is necessary to settle for a qualitative classification in terms of high, medium and low; or explicit statements concerning the disruption likely to be suffered (Coburn et al., 1994). Susceptibility is defined as the propensity or tendency of an area to be affected by the occurrence of a given hazard (Ayala-Carcedo, 2002). The categories used for a susceptibility analysis can be (Rauld et al., 2015): (1) Very High; there are very favorable conditions and there are several recorded events, (2) High; there are favorable conditions and there are sporadic events recorded, (3) Moderate; there are some favorable conditions and / or practically no catastrophes of danger and (4) Low / Null; no favorable condition to some event. Hence, susceptibility and vulnerability mapping are considered one of the most important steps in disaster risk reduction because it identifies elements (areas and communities) propensity to be affected by a disaster, they are important for disaster risk management planning (Isma'il and Saanyol, 2013).

Hazard risk vulnerability mapping is considered one of the most important steps in disaster risk reduction because it keeps identifying vulnerable areas to be considered into plans for disaster risk management (Isma'il and Saanyol, 2013). Next level to risk maps are the susceptibility and hazard maps as expression of the probability of occurrence of a certain event in a location and period of time, the higher level corresponds to maps that take into account not only the phenomena themselves and their probability but how they affect people and goods (exposure) and its economic, psychological and social valuation, or in terms of the degree in which they are affected (vulnerability); finally, the product of the hazard, elements at risk valuation and vulnerability results in risk assessment (Fernández et al., 2013).

Different tools are available to make susceptibility and vulnerability maps; we have the traditional ones related to cartography, topographic and geographic, which make maps of the location of the threats (plate tectonics, mountain streams, soil types, etc.). Others include new technological tools available today with mobile communication devices such as those with a geographic system integrated with GPS, remote sensing and fuzzy logic to generate a real-time evaluation or simulation to determine the presence of contaminating sources of impact (Corwin et al., 1996). Vulnerability mapping is also done in the frame to understand social vulnerability and to more easily identify areas of vulnerable population (IWR, 2013).

However, technology still has limitations and obstacles, such as the case of digital cartography, whose main challenge is to achieve preventive analysis of threats, based on reliable approximation of data from different hazards on the same space (Perles and Cantero, 2010). As well as an important amount of high-quality data to be able to analyse and elaborate valid and reliable vulnerability maps (Esteller et al., 2002). To overcome some problems mentioned, the use of drones is proposed as an alternative to play an important role, in obtaining data and information related to the mapping of vulnerabilities in a territory exposed to threats. This advanced equipment of hardware and easy manoeuvrability allows the capture of large amounts of information thanks to the various integrated sensors (Ramírez et al., 2013).

To acquire situational awareness of the disaster an accurate map and 3D model of the affected terrain can be obtained using aerial images and photogrammetry techniques. Such images have been obtained using drone technology in two phases using different kind of aircraft: fixed wing and multirotor. Each one is used for specific missions depending on the type of mapping required.

The paper is organized as follows, first the theoretical framework based on the understanding of geographic information systems (GIS) will be presented, then the systems of drones for the use of disaster monitoring, shortly after the contribution of this work, which is the development of maps of vulnerability and prognosis of some affected areas for the study area. Finally, the discussion and conclusions parts, adding proposals of future works of investigation, are presented.

GEOGRAPHICAL INFORMATION SYSTEM (GIS)

Rodríguez-Espíndola et al. (2016) show the capabilities of Geographical Information System (GIS) for disaster management and the analysis potential flooding scenarios to provide information for an optimization model of location and distribution. The work is applied to two real-world floods in Mexico. The results provide evidence that including GIS analysis for a decision-making tool in disaster management can improve the outcome of disaster operations by reducing the number of facilities used at risk of flooding. Cutter (2003) highlights the applications of GIS to the emergency response cycle, citing examples from natural hazards and suggests some important research areas based on the needs of the disasters and emergency management. Other studies on information systems applications, vulnerability and risk mapping in humanitarian logistics can be found in the literature: Chen et al. (2018); Hu et al. (2016); Isma'il and Saanyol (2013); Kumar and Anbalagan (2015); Muthukumar (2013); Özdamar and Ertem (2015); Tomaszewski et al. (2015). GIS applications in Disaster Management are progressively turning into a necessary component of disaster and emergency management activities in many parts of the world. The spatial dimension of geospatial data makes it exceptionally critical for decision-makers in the different phases of emergency management operations. It is important for policy makers to have the right information to permit them to react, mitigate and manage catastrophes (Abdalla, 2016).

DRONE SYSTEM IN DISASTER RISK MANAGEMENT

Unmanned Aerial Systems (UAS) have considerable potential to radically improve monitoring. UAS-mounted sensors offer an extraordinary opportunity to bridge the existing gap between field observations and traditional air and space-borne remote sensing, by providing high spatial detail over relatively large areas in a cost-effective way and an entirely new capacity for enhanced temporal retrieval (Lin et al., 2016, Manfreda et al., 2018, Tanzi et al., 2014).

Elaboration of vulnerability maps by drones have numerous benefits to support decision-making for reducing the vulnerability of communities, through utilisation of information to mitigate or reduce the impact of social disasters (Ismail-Zadeh and Cutter, 2015), and taking care of vital infrastructure such as electricity, water, transport, health and safety (Sandholz, 2018). Other ones applied in poor communities and their surroundings are the monitoring and execution of action plans, the simulation of models for the prevention of disasters, improvement in the precision and quality of urban-environmental planning and the relatively fast speed of data is collected (UNEP-DHI Partnership, 2017).

Based on experience from the authors, who deal with drone projects in different applications related to agriculture, cartography etc. (GISANT, which is the Unmanned Aircraft Systems Research group at Pontifical Catholic University of Peru, PUCP, http://investigacion.pucp.edu.pe/grupos/gsant/ and the National Telecommunications Research and Training Institute, INICTEL, a research group from National University of Engineering, UNI, http://didt.inictel-uni.edu.pe/didt/index.php/grupo-de-procesamiento-de-senales-e-imagenes-g-psi/) with the support the Crisis and Disaster Management group at PUCP, an interinstitutional and multidisciplinary (industrial, electronic and mechatronic engineers) research group to deal with this project was created. Three main phases are proposed to run a drone-mapping project. The first phase of the drone-susceptibility mapping project involves the acquisition of data from a wide area perspective, to swiftly acquire information on a large scale. For this task, a fixed wing aircraft is used. Images are acquired and are processed using of the shelf software to obtain 3D models and mapping. These maps will be crucial to detect affected areas by potential landslides; these specific sites need to be properly mapped in more detail, for which the second phase is put into operation. The second phase involves the use of multirotor aircraft which can fly lower and acquire detailed data to assess the situation and provide the necessary information for relief decision making. A final third phase relates the processed image information with previous threat conditions as cliffs, unsteady slopes, type of soil, presence of ravines, etc. which create susceptibility conditions and let identify potential affected by future landslides to be triggered by the increase of raining periods like El Niño phenomenon.

SYSTEM OVERVIEW

According to the report of the National Emergency Operations Center, COEN (2017) in Peru, since January 14, 2017, heavy rainfall was recorded because of the presence of Coastal El Niño, affecting the districts of Lurigancho-Chosica and Chaclacayo in Lima (Peru's capital), causing huaicos, affecting homes, communication routes, educational institutions and damage to the life and health of people. On March 16, 2017, at 4:30 p.m., the overflow of the waters of the Jicamarca ravine (Huaycoloro River) was recorded, and at 9:00 p.m., the overflow of the Rímac River was reported, causing the affectation of road bridges, housing, public places, communication routes and flooding in several sectors of the districts of San Juan de Lurigancho, El Agustino, Lurigancho-Chosica. On March 19 at 12:30 a.m., because of the intense rainfall, the Chillón River overflowed also, affecting cultivation areas in Carabayllo sector.

According to information found at the search engine service for information on disasters and their impact in Peru (see Figure 2), named the National Information System for Response and Rehabilitation, SINPAD (http://sinpad.indeci.gob.pe/sinpad/Estadistica/Frame_Esta_C7.asp) from the National Institute of Civil Defense of Peru, INDECI ; it was selected the town of Huatocay and its surroundings, in the district of Carabayllo as the study area because of 3450 casualties reported (see Figure 3). With the support of a seed fund of research by Penn University, researchers from UNI and PUCP, teamed up to design a humanitarian supply chain to 2017 Coastal El Niño affected communities from Huatocay. It was determined by the research group that the starting point would be to identify susceptibility areas to landslides. To carry out the field work, contact was made with the authorities and local inhabitants to receive support for the search of the appropriate places to be used for the drone flight work. Other benefits of the inclusion of authorities and residents in the realization of these works, are the transfer of knowledge and experience for disaster management, through the management of drone flight equipment, evaluation of areas of risk, control of existing threats, etc. The limitations for the development of this population inclusion strategy, to carry out the fieldwork has to do with the level of education and budget of the local authorities to carry out disaster prevention activities.

Figure 2. The National Information System for Response and Rehabilitation, SINPAD

Figure 3. Huatocay location in Carabayllo, Lima region, Peru

Phase One: Fixed Wing Aircraft

The system features an 1880 **-** Skywalker aircraft frame. It is described as a flying wing UAV model made of highly dense foam and it has four main components: one fuselage, one elevon and two wings. Figure 4 shows the frame of the current prototype. This type of UAV has control surfaces on the wing as ailerons, horizontal and a vertical stabilizer on the tail as elevator and rudder to control roll, pitch and yaw during flight. The fuselage or main body was modified to house the Avionics, Propulsion and the Image Acquisition Systems components. Figure 5 shows an overview of the entire system.

Figure 4. 1880 - Skywalker UAV model for multipurpose appliances

Avionics System

The Avionics System is built around the Pixhawk2 autopilot from Hex Technology Limited, whose tasks include the control of all the actuators of the UAV, reception of sensor information for state feedback for the system control algorithm, trajectory planning, and signal reception from the Ground RC Controller, among others. The Pixhawk2 controls each surface of the aircraft to follow the flight plan that is uploaded before each flight. The control algorithm used is based on PIDs that synchronize the movements of the electric servos on each control surface on the wings to follow the designated waypoints on the flight plan. Each waypoint has a known altitude, latitude and longitude coordinate that it is used to guide the UAV. For this purpose, the Pixhawk2 uses several important components, which will be described in the following paragraphs:

- A GPS Receiver, to get the UAV's geographical location and heading in the world.
- An Airspeed sensor, to get the current wind airspeed (and consequently the UAV speed) and calculate the altitude from pressure data.
- A telemetry radio, to inform a Ground Station about the status of the UAV and the mission.

- A RC Receiver, to get the RC signals from a ground controller for manual control of the UAV and to receive the command to start autonomous flight.
- An embedded IMU, for information regarding UAV attitude.
- An embedded barometer, to calculate the pressure altitude over sea level.

Figure 5. An overview of the fixed-wing UAV proposed system

Propulsion System

The Propulsion System is responsible for generating the thrust required by the UAV to move forward and control the speed of the aircraft, which is important to generate enough lift during take-off operations. Its main components are one Turnigy Motor ® 700KV brushless motor, one 4S – 8000mAh Li-Po battery and a 10″×7″ foldable plastic propeller.

Image Acquisition System

For the task of acquiring and storing images, a Sony NEX 7 camera is used to capture of 24.3 megapixels images. The Pixhawk2 navigation controller sends the necessary signal to trigger the camera.

Methodology for Data Acquisition and Processing

This part is composed of the following sub steps planning and operations: terrain inspection for take-off and landing operations, flight planning for trajectory, 3D reconstruction and surface flow model.

Terrain Inspection for Take-Off and Landing Operations

After arriving at the area of operations, the surrounding environment must be inspected to determine suitable terrain for the Take-Off and Landing Operations. A smoother land of considerable extension must be found to carry out a successful landing. Moreover, take-off operations, although not as dangerous as landing ones, require a place where the ground offers stable footing since, propulsion must be provided by a human operator, who must gain speed by running and throw the aircraft while the pilot activates the throttle.

Flight Planning (Trajectory Determination)

Test flights were carried out near Chillón River in Perú over two regions (76°58'58.713"W, 11°43'55.006" S) and (76°56'21.394"W, 11°42'28.940" S) on March 28, 2018. Each flight plan was made using the Mission Planner software considering a 75 percent overlap between images and flight lines. The terrain and weather are important factors to consider during the preparation of each flight plan. To overcome these difficulties, the flight plans are designed so that the UAV will fly alongside the direction of the wind and against it when the wind speed is relatively low to save energy. To determine where the photos are to be taken along the trajectory, a distance-based system is employed, meaning that the cameras will be triggered each time the aircraft travels a determined distance inside the area of interest. This allows the images to maintain the desired degree of overlap since they are taken at regular position intervals, unaffected by wind speed or aircraft velocity. Moreover, flight trajectory is also determined by the image resolution of the camera. In Figure 6, the flight trajectory for the flying missions of two areas near Chillón River is shown. For these flights, a relative altitude of 150 meters was chosen, so to cover the entire area, the trajectory could afford to be sparse and with few lines for the aircraft to go through.

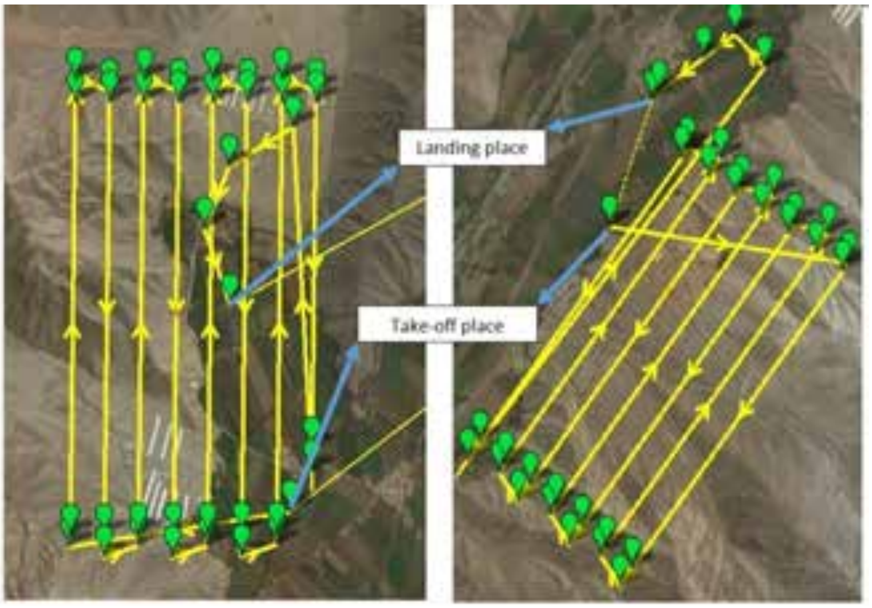

Figure 6. Flight trajectory of the two flying missions using Mission Planner software

3D Reconstruction

After performing the flights and acquiring images, a photogrammetry software was used to reconstruct the terrain that was overflown. Agisoft Photoscan software was used to process the images and generate 3D models and digital elevation models (DEM). The 3D models and DEMs of the two regions subject of this study are shown in Figures 7 and 8.

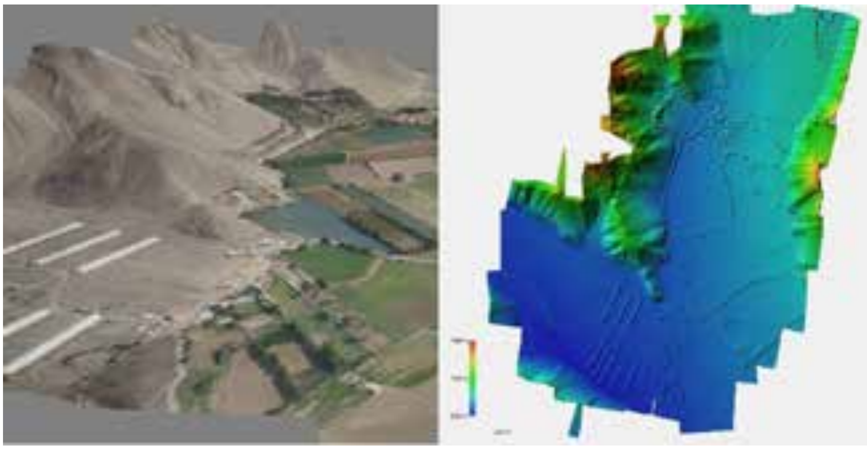

Figure 7. 3D reconstruction – Zone 1, scale 1:500

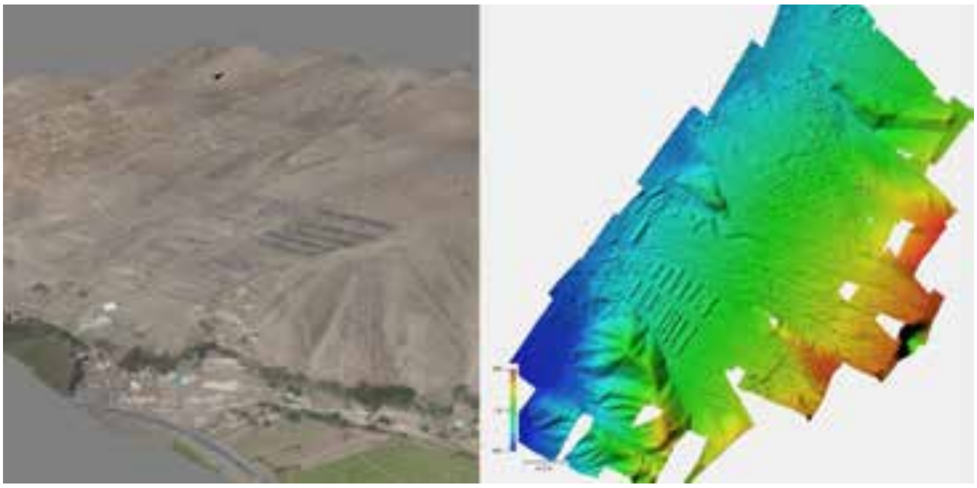

Figure 8. 3D reconstruction – Zone 2, scale 1:1000

Surface flow model

A surface flow model is needed to assess the possibility of a landslide event. It can be obtained by means of processing the Digital Elevation Models obtained from the previous procedure. The D-infinity algorithm, proposed by David G. Tarboron, was implemented using Matlab software for each DEM.

Phase Two: Multirotor Aircraft

The system features a Turbo Ace Matrix-E aircraft frame. It is described as a quadcopter UAV model made of carbon fiber deck which supports a 1000 mm wingspan and it has two main components: one frame consisting of 2 Carbon fiber Structural Beams and 4 15" T-Motor Precision Propellers.

Avionics System

The Avionics System is built around the Naza-M V2 Flight Controller from DJI, whose tasks include the control of all the actuators of the UAV, reception of sensor information for state feedback for the system control algorithm, trajectory planning, signal reception from the Ground RC Controller, among others. For this purpose, the Naza-M V2 Flight Controller uses several important components:

- GPS & Compass Functions include GPS-Lock, Home-Lock, Course-Lock & Return-to-Home.
- Transmitter & Receiver Recommendation: 2.4GHz.
- A RC Receiver, to get the RC signals from a ground controller for manual control of the UAV and to receive the command to start autonomous flight.
- An embedded IMU, for information regarding UAV attitude.
- An embedded barometer, to calculate the pressure altitude over sea level.

Propulsion System

The Propulsion System is responsible for generating the thrust required by the UAV to move forward and control the speed of the aircraft, which is important to generate enough lift during take-off operations. Its main components are 4 Dynamically Balanced Brushless Motors, one 16,000 mAh 25C 6S (22.2V) LiPo Battery and four 40A ESCs with Cooling Algorithm.

Image Acquisition System

A Sony NEX 7 based camera system is used to capture images of 24.3 megapixels. It includes a Gyrox-7+VTX gimbal for camera stability.

Terrain Inspection for Take-Off and Landing Operations

After arriving at the area of operations, the surrounding environment must be inspected to determine suitable terrain for the Take-Off and Landing Operations. A smoother land of minor extension is considered to carry out a successful landing. Take-off operations, although not as difficult as in the fixed wing case, require a place where the ground offers stable footing.

Flight Planning (Trajectory Determination)

Test flights were carried out in the town of Huatocay near Chillón River in Perú (76°59'10.9''W, 11°45'24.7''S) on March 28, 2018. In Figure 3, the flight trajectory for the flying mission over Huatocay is shown. For these flights, a relative altitude of 70 meters was chosen, so to cover the entire town.

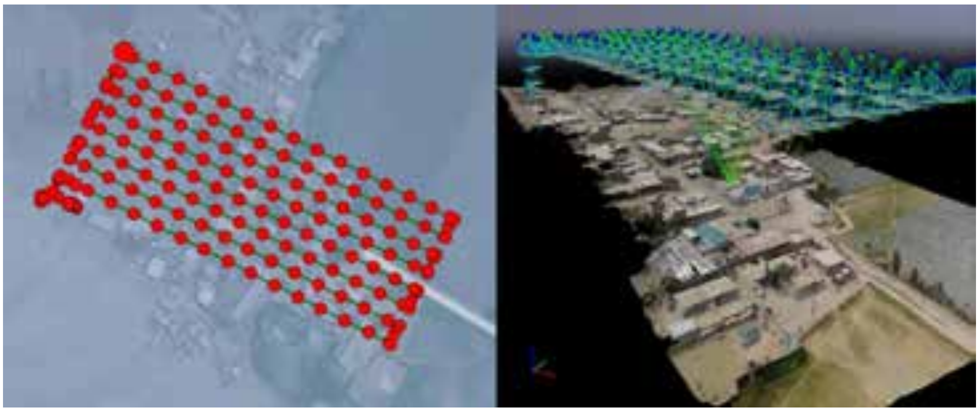

Figure 9. Flight trajectory for 3D reconstruction of Huatocay

3D Reconstruction

After performing the flight and acquiring images, photogrammetry software was used to reconstruct the terrain that was overflown. Pix4DMapper Pro software was used to process the images and generate a 3D model and a digital elevation model (DEM). The 3D model and DEM of Huatocay are shown in Figures 9 and 10.

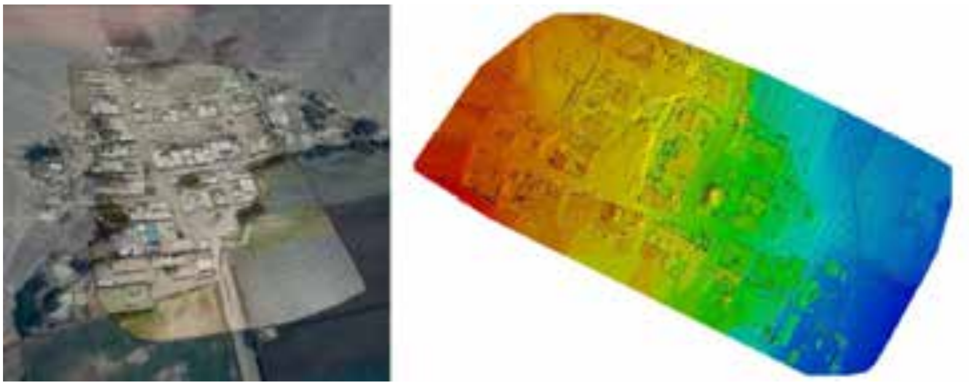

Figure 10. 3D model and DEM of Huatocay

Phase Three: Vulnerability conditions identified

Surface flow model

A surface flow model is needed to assess the possibility of a landslide event. It can be obtained by means of processing the Digital Elevation Model obtained from the previous procedure. The D-infinity algorithm, proposed by Tarboron (1997), was implemented using Matlab software for each DEM. Figure 11 shows the flow model example in red which represent potential landslide to be triggered with critical conditions such as rainfall and type of soil. This model has a close relationship with the landslide events occurred in 2017.

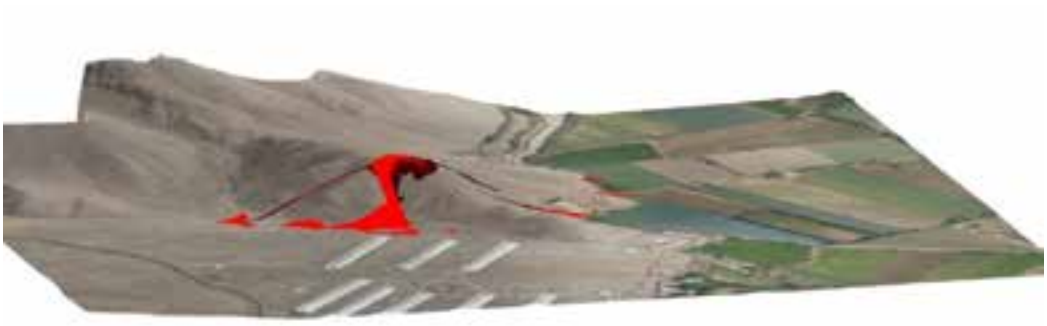

Figure 11. Surface flow models obtained, scale 1:500

DISCUSSION

In this work, we propose the use of Unmanned Aerial Vehicles and Digital Image Processing Software to give additional information for Disaster Risk Management purposes. The combination of these new technologies allows the user to build 3D models, digital elevation models, orthomosaics and other products that can be studied in a GIS. In comparison with traditional methods to obtain this kind of information, such us topography, the use of UAVs and photogrammetry software is a more efficient way because of time, budget and precision. Depending of the type of UAV, the mapping of certain areas can be made in less than the quarter of time spent by traditional methods. Moreover, the cost of conventional method can be three times the cost of UAV based methods (Volkmann, 2017), also using RTK points, the precision reached by the photogrammetry software is in the order of millimeters.

Albeit, the use of UAV and software to process the images possesses some important points to take in consideration. Nowadays, people need a license to pilot these vehicles in many countries, and it expresses some restrictions about the area to fly or other conditions. In addition, not all the kind of UAVs can be used to map specific areas, it requires technical information to plan the autonomous flight. Finally, when the images are acquired, it is required to use a software to build the 3D models and other products. This software is an additional expense and it is also needed to have a basic knowledge of photogrammetry to use them.

For this study, we evaluate this advantages and drawbacks related to these technologies and we are convinced that this methodology should be used because of the continuous development of UAV technology and the availability of them. The municipality of Carabayllo has recently acquired two UAV with the capabilities to map the area of study. Besides, they have been trained to use properly the UAVs, and now they are planning to acquire the license of photogrammetry software to process their images. For these reasons, we consider that this new methodology is a suitable solution to perform aerial mapping for Disaster Risk Management purposes.

CONCLUSION

The results of the information processing allowed to elaborate the susceptibility maps of the area under study, establishing potential area where material flow landslides would occur, the results found allowed to find a correspondence between the information of the affected areas due to of the Coastal Child in 2017 according to SINPAD information and the estimations obtained from the processing of the images shown in the present work.

A new version of this work should include in addition to the degree of slopes a characterization of the territory that includes the levels of risk of the area associated with the characteristics of the type of soil, configuration of the city and amount of rainfall in the study area. It is known in the literature that the landslides and their impact are the result of a more complex system that corresponds to the interaction of all these characteristics, achieving different results according to the state of the criterions, in this way it will be possible to establish at micro level the flow of landslides with more certainty. These categories can also be included considering their historical performance in a cause-effect relationship with the activation of landslides that occurred in the study area.

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