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Forced disappearances and missing people in Colombia, South America

Carlos Martín Molina [a,b,*], Daniel Castellanos [c], Alejandra Baena [d], Angela Salgado [e], Jamie Pringle [f]

[a] Laboratorio de Evidencia Traza, Instituto Nacional de Medicina Legal y Ciencias Forenses y, Colombia
[b] Facultad de Ingeniería Ambiental y Civil, Universidad Antonio Nariño, Colombia
[c] Laboratorio de Antropología Forense, Instituto Nacional de Medicina Legal y Ciencias Forenses, Colombia
[d] Facultad de Ciencias, Universidad Antonio Nariño, Colombia
[e] Antropóloga Forense, Consultora, Colombia
[f] School of Physical Sciences & Geography, Keele University, Staffordshire ST5 5BG, UK

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1. Introduction

The Rome Statute of the International Criminal Court (2002) establishes that the enforced disappearance of persons "means the arrest, detention or abduction of persons by, or with the authorization, support or acquiescence of, a State or a political organization, followed by a refusal to acknowledge that deprivation of freedom or to give information on the fate or whereabouts of those persons, with the intention of removing them from the protection of the law for a prolonged period of time" [1].

In Colombia, the first records of forced disappearances can be tracked back to the 1970 s. Due to social protest and strikes, at the end of 1977 the military publicly demanded "emergency measures" against subversion. Thus, the Colombian government issued decree 1923 in 1978, the National Security Statute 1978–1982 (Estatuto de Seguridad Nacional), which aimed to stop current guerrilla groups, social protest and social movements. However, this decree gave the power for arbitrary arrests, torture, retention and forced disappearance of civilians, with an estimate of more than 3000 people that this happened to. [2–4]. Thus, forced disappearances became a "common" practice, protected under this decree [5].

Among efforts to fight against enforced disappearances and find the missing, in 1979 there was created The Permanent Committee for the Defense of Human Rights [Commité Permanente por la Defensa de los Derechos Humanos (CPDH)]. However, its leaders were persecuted and several of them were assassinated [3,5]. After the decree was repealed, in 1983 civil groups were created to fight against forced disappearances and impunity, one of them is the Association of Relatives of Disappeared Detainees [Asociación de Familiares Detenidos Desaparecidos (ASFADDES)], that was created as a result of the search of 14 disappeared persons: 12 students from the National University, 1 worker and 1 peasant community leader, during March to September 1982 [6].

In 1985, during the Palace of Justice siege, an attack on the Supreme Court of Colombia by members of the leftist M-19 guerrilla group, 94 people were killed and 12 disappeared, most of them were employees of the cafeteria and visitors. Recent investigations, looking for answers for the whereabout from those who left the building (Palace of Justice) alive, have focused on information from testimonies collected by the truth commission and the images analyzed by the interdisciplinary forensic investigation group Forensic Architecture, which evidenced human rights violations [7].

In 2014, the Inter-American Court of Human Rights (IACHR)

Abbreviations: IACHR, Inter-American Court of Human Rights; ASFADDES, Asociación de Familiares Detenidos Desaparecidos; CPDH, Commite Permanente por la Defensa de los Derechos Humanos; CBPD, Comisión de Búsqueda de Personas Desaparecidas; FARC-EP, Revolutionary Armed Forces of Colombia- People's Army; EPL, Popular Liberation Army.

* Corresponding author at: Laboratorio de Evidencia Traza, Instituto Nacional de Medicina Legal y Ciencias Forenses y, Colombia.
E-mail address: cmolina@medicinalegal.gov.co (C.M. Molina).

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condemned the Colombian State for disappearances, torture, and extrajudicial executions, which occurred after the Palace of Justice siege, and requested to investigate the details regarding what happened in order to establish the truth [8].

Colombia has experienced an internal armed conflict for decades between different actors which includes illegal organizations (i.e., guerrillas and paramilitaries), drug traffickers and organized crime groups [9]. These actors have inflicted different forms of violence to the population used as war strategy such as, forced disappearance, selective homicides, tortures, massacres forced displacement and sexual violence, which are included in human rights and international humanitarian law violations (IHL) [10,11].

Thousands of missing persons, deaths and unidentified bodies have resulted from this violence. Therefore, the Colombian government has been forced to stablish laws in order to strength institutions and attend victims, families of the victims, identify the deceased and prosecute the perpetrators.

Colombian legislation fits the protection of victims of International Armed Conflicts as established in The Geneva Conventions of 1949 and their additional Protocols. For instance, in Judgment No. C- 574/92 (1992) of the constitutional court, it is stated that the dead are searched for, recovered and identified in the areas where the battles take place. [12].

The Political Constitution of 1991 acknowledged forced disappearances, but until 2000, with Law 589, the families of forced disappearances, who encouraged the law, had the judicial framework for the crime investigations and the search for the whereabout of their loved ones. This law penalized the forced disappearance crime, and this is also related to genocide, forced displacement, and torture. Other mechanisms for the search of the missing people were created such as the Search Commission for Missing Persons (Comisión de Búsqueda de Personas Desaparecidas [CBPD]) with the National Plan of Missing Persons (Plan Nacional de Búsqueda de Personas Desaparecidas [PNBPD]); the National Registry of Missing Persons (Registro Nacional de Desaparecidos [RND]); the Urgent Search Mechanism [Mecanismo de Búsqueda Urgente (MBU)] and assets management of the missing persons [13]. The CBPD and the RND began to be effective years later, in 2005 and 2007, respectively [14].

The Inter-American Convention on Forced Disappearance of Persons, held on June 9, 1994 in Brazil, established that the States Parties should provide reciprocal cooperation in the search, identification, location and return of minors who have been moved to another State or retained there, as a consequence of the forced disappearance of their parents, tutors or guardians. [15]. Colombia incorporated it through Law 707 of November 28 of 2001 [16], which is formalized with Decree 3974 of November 8, 2005 [17].

The Colombian Law 1418 of 2010 and the Constitutional Courtś Judgment C-620/2011, approves the "International Convention for the Protection of all Persons against Enforced Disappearances", which highlights: the right of not to be disappeared; the definition of forced disappearance by state and parastate agents and forced disappearance as a crime against humanity. The investigation of the crimes is mentioned; cooperation between States for the search; the collection of genetic or medical data for the search; the rights of victims and family members, and the disappearance and appropriation of children [18].

Since the 1980 s, Colombia has initiated different peace processes with the different armed actors of the conflict: with the Revolutionary Armed Forces of Colombia- People's Army (FARC-EP), with the EPL (popular liberation army), the Quintín Lame and the PRT (revolutionary party of the workers); with the Simón Bolívar Guerrilla Coordination (CGSB) in Caracas and Tlaxcala; with the Socialist Renovation Current (CRS); with the ELN in the Palacio de Viana; [19] with the United Self-Defense Forces of Colombia-AUC, the latter gives rise to what was called the Law of Justice and Peace, which corresponds to transitional justice framed in Law 975 of 2005 "By which provisions are issued for the reincorporation of members of armed groups organized outside the law, who contribute effectively to the achievement of national peace and other provisions are dictated for humanitarian agreements" [20]. This law also dictated the mechanism to search for the missing, the identification of those who were deceased, and the return of their remains to their families to be buried, according to their family and community traditions (Article 48, 49.2).

In 2016, the "Final Agreement for the Termination of the Conflict and the Construction of a Stable and Durable Peace" was signed between the Colombian government and the Revolutionary Armed Forces of Colombia [Fuerzas Armadas Revolucionarias de Colombia (FARC)].".

Point 5 of this document, "conflict victims" mentions the creation of the Comprehensive System of Truth, Justice, Reparation and Non-Repetition. Thus, the Comprehensive System for Peace is composed with the Commission for the Clarification of the Truth [Comisión para el Esclarecimiento de la Verdad (Comisión)], the Special Jurisdiction for Peace [Jurisdicción Especial para la Paz (JEP)] and the Search Unit for Disappeared Persons [Unidad de Personas dadas por Desaparecidas (UBPD)].

The UBPD is formalized under Decree 589 of 2017 "by which the Search Unit for Persons given as Disappeared is organized in the context and due to the armed conflict" [21], with international support of international organizations such as, the International Committee of the Red Cross (ICRC), the International Commission on Missing Persons (ICMP) and Sweden. [22] whose main objective is "to establish the universe of considered missing people in the context and due to the armed conflict" [23].

Likewise, it established the creation of "a special chapter of the National Registry of Disappeared, managed by the National Institute of Legal Medicine [Instituto Nacional de Medicina Legal y Ciencias Forenses (INMLCF)], exclusively for the universe of missing persons disappeared in the context and due to the armed conflict" [24].

2. Data on forced disappearance and missing people

The investigations carried out by the National Center for Historical Memory [Centro Nacional de Memoria Histórica (CNMH)] show that in the Colombia armed conflict, the vast majority of victims are the non-combatant civilian population, which clearly exhibit the degradation of the war and violations of the humanitarian norms. In the country, these deaths have occurred on a daily, selective and silent basis in rural areas far away from urban centers. Thus, it is easy that these deaths get unnoticed by the majority of society; deaths that have been accompanied by cruelty and terror. [10].

Data from the Observatory of Memory and Conflict[1] [Observatorio de Memoria y Conflicto (OMC)], mentions that of the 80,733 victims of forced disappearance in the period 1958–2021, 79.488 were civilians, 1,232 combatants and 13 people were unknown [25]. The Victims Unit (Unidad de Victimas) from Colombia through its Unique Registration System [Registro Único de Victimas (RUV)] records 9,278,531 victims from which 1,907,502 are deceased, direct victims of forced disappearance and homicide [26].

Different institutions have been collecting information and building missing persons datasets. This is a difficult task due to the magnitude of the forced disappearance in the country, and because of this, it is still an ongoing social issue.

The collected data may vary between institutions, this is in part due to the objectives of each of them (e.g., judicial, humanitarian, etc.) see Table 1. However, the estimated number of missing persons in Colombia is around 120,000 [27,28]. It is also important to keep in mind that there is underreporting of cases due to different reasons. For instance, many victims experience fear due to threats, and they do not report the forced disappearance of their loved ones; in other situations, the entire family

[1] The OMC is a unit of the National Center for Historical Memory [Centro Nacional de Memoria Histórica (CNMH)].

Table 1
Different dataset resources of forced disappearances and missing people for Colombia. RND = Registro Nacional de Desaparecidos, OMC = Observatorio de Memoria y Conflicto, RUV = Registro Único de Victimas, UBPD = Unidad de Personas dadas por Desaparecidas, SPOA = Sistema Penal Oral Acusatorio, see text for details.

Source	Dates	Missing people	Forced disappearances	Still missing	Found alive	Found dead
RND	1903–2021	167,325	33,318	111,660	47,023	8,664
OMC (CNMH)	1958–2021	–	80,733	70,620	1,794	8,308
RUV	1985–2021	–	50,604	–	–	–
UBPD	1921–2016	80,420	99,235	–	–	–
SPOA	1968–2021	–	101,272,	–	–	–

have been murdered, and thus there is not any family member to report a case to the authorities. Other people just do not believe in justice.

The medicolegal authority in Colombia responsible for the identification of the deceased is the National Institute of Legal Medicine and Forensic Sciences [Instituto Nacional de Medicina Legal y Ciencias Forenses (INMLCF)]. Since 2007, this institution uses the Network of Missing Persons and Cadavers [Sistema de Información Red de Desaparecidos y Cadáveres (SIRDEC)] an information system to register national information from medicolegal autopsies, which includes postmortem information from unidentified bodies, and antemortem information of missing persons. This institution also manages the National Registry of Missing People [Registro Nacional de Desaparecidos (RND)] a national and interinstitutional information system, which includes the SIRDEC, and aims to the identification of autopsied bodies, the guide of the search of missing persons, and the activations of the urgent search mechanism (MBU). Another institution involved with the search, recovery, and analysis of human remains (i.e., skeletonized human remains) is the Technical Investigation Team [Cuerpo T é cnico de

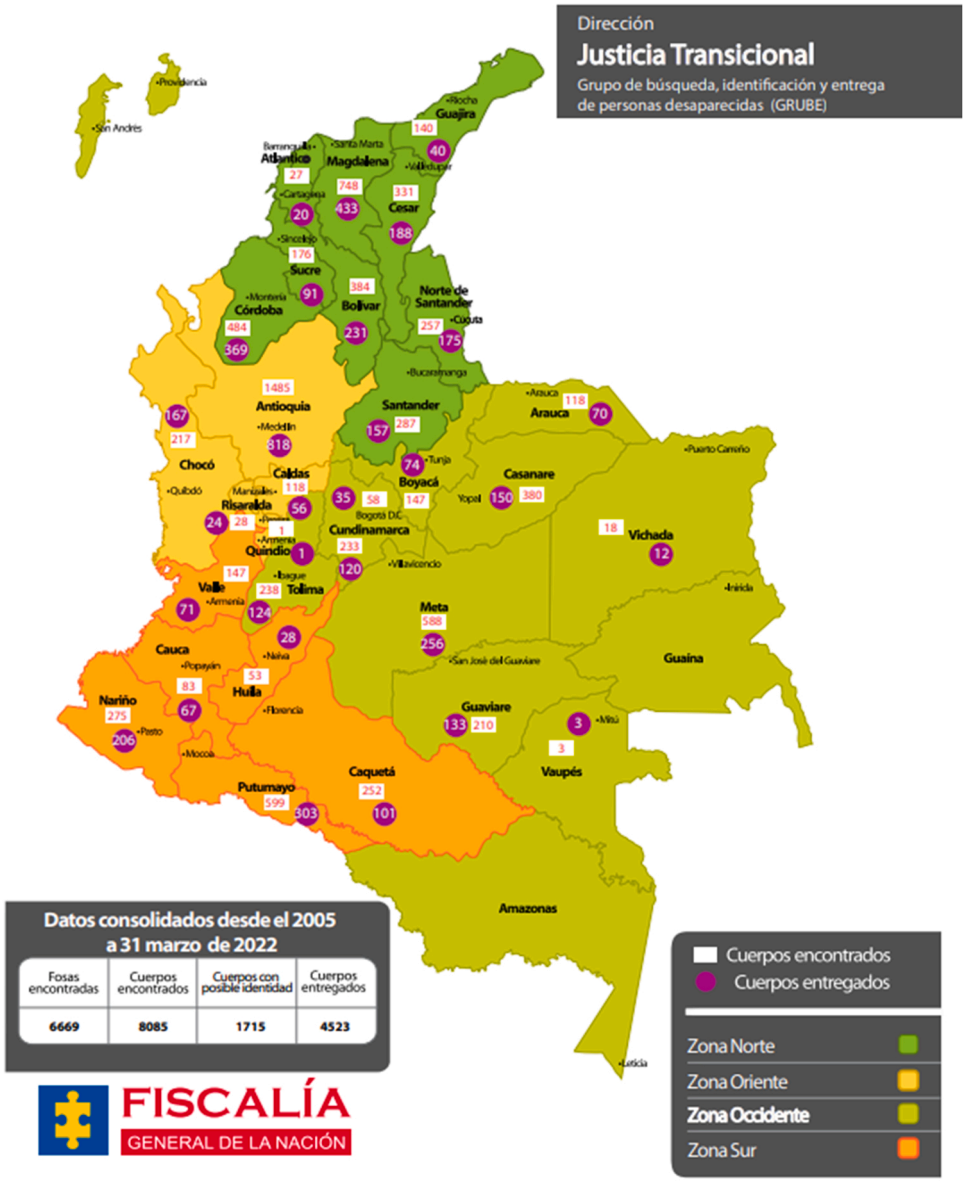

Fig. 1. Map of Colombia with the number of human remains found in graves, from 2005 to March 31, 2022. From https://www.fiscalia.gov.co/colombia/wp-content/uploads/2022–03–31-reporte-grube.pdf.

Investigación (CTI)] of the National Attorney General's office (Físcalia General de la Nación).

Colombia faces a humanitarian challenge to find the missing and identified those who are found dead. The lack of unique source of missing databases to avoid duplication or not-reported cases, as well as the violence where bodies were buried in clandestine graves, thrown into rivers, dismembered, cremated or buried in cemeteries [29] are factors that contribute to many families still waiting to know the whereabouts of their loved ones remains.

The National Attorney General's office (Físcalia General de la Nación) has been tasked with carrying out the search, recovery, identification and return of missing persons throughout Colombia. From 2005 to 2022 they have found 6,699 graves and 8,085 bodies (Fig. 1). From 2010 to 2022 they have recovered 2,906 remains (Fig. 2) from cemeteries [30]. Despite these efforts thousands of recovered bodies still remain unidentified.

The Inter-institutional Agreement 001–2010 in 2010, was a cooperation between the National Civil Registry, the Ministry of Internal Affairs, and the INMLCF of Colombia. Its main objective was to identify around 22,689 unidentified bodies (previously autopsied) for the period between 1970 to 2010, buried in official cemeteries as unidentified [31].

The missing situation in the country, indicates that, despite the actions that have been carried out in the search for the disappeared by the Colombian State, there is a great mismatch between the official minimum number of 120,000 disappeared (Red Cross), and the relatively few identified remains found. Therefore, there are thousands of relatives who continue to wait to find their missing loved ones. It is thus necessary to increase search groups which includes the participation of both geosciences and the use of technology, as will be seen later.

3. Multidisciplinary methods to detect clandestine graves

Due to the serious problem of the missing people as mentioned, in addition to the usual forensic intelligence-led search methods which lead to 90% of the cases being through testimonies, the need to implement the search for the disappeared using search technology arises. This may significantly increases the probability of discovery, so it is possible to search faster for clandestine graves, and for the remaining 10 %,

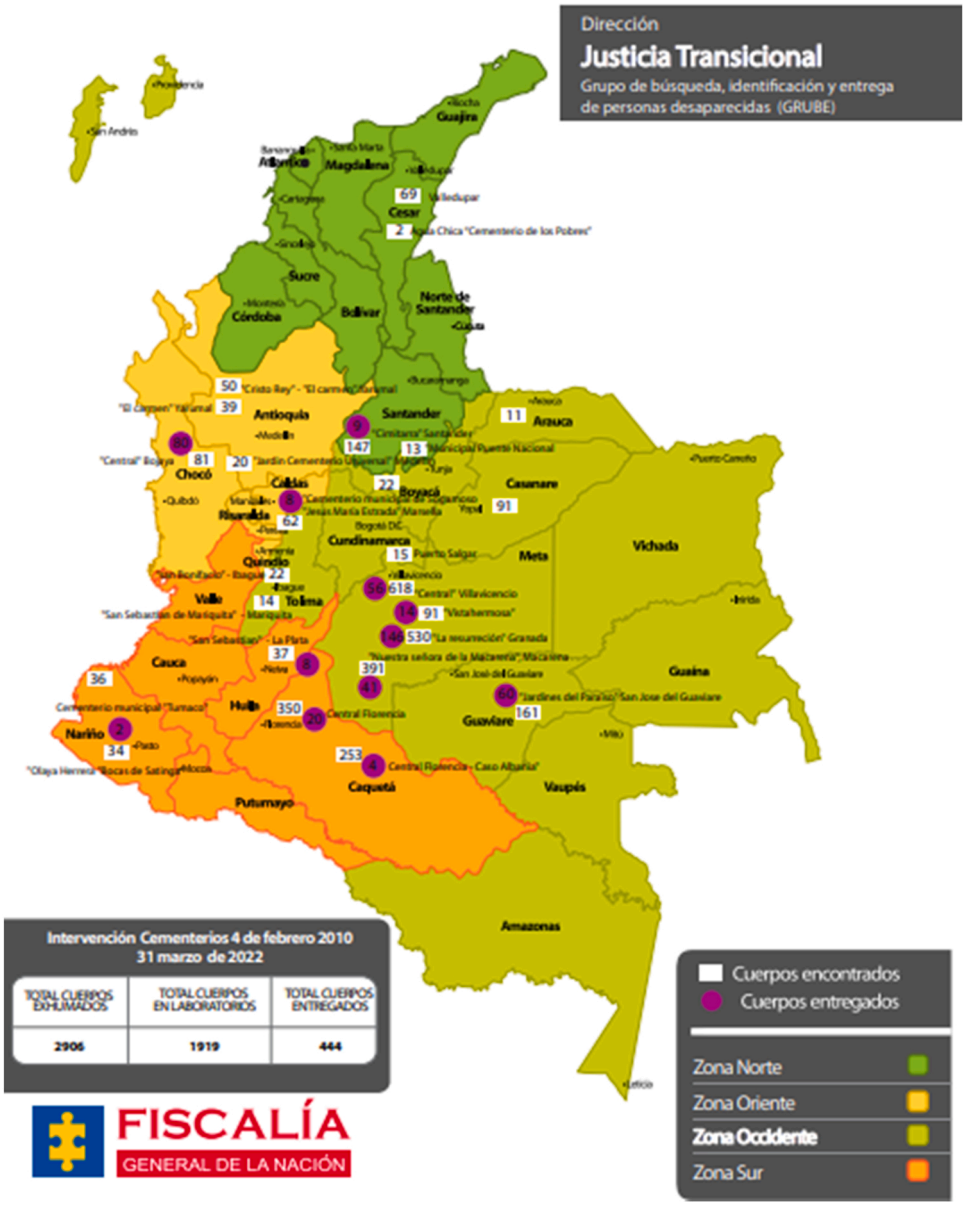

Fig. 2. Map of Colombia with the number of human remains found, from 2010 to March 31, 2022. From https://www.fiscalia.gov.co/colombia/wp-content/uploads/2022–03–31-reporte-grube.pdf.

approximately 12,000 people. The proposal is that, in order to achieve this objective, the judicial police search groups in the country are complemented with professionals in geosciences, and more rigorous search methods is carried out before and during the field work, as well as with the subsequent interpretation of the results obtained. with the use of specialised search equipment.

Therefore for this, the efforts of specialised researchers in various Universities, sometimesin cooperation with the private sector, have focused on the evaluation of the efficiency of different search methods based on technologies to determine their efficiency for the detection of clandestine graves. It is important to note that the assessment has required the development of research projects that support the results, which may be considered in the protocols of the judicial commissions used for the searching for missing people.

The main features of some forensic controlled experimental projects in zones of Colombia are presented. Their purpose have been focused on generating new knowledge in the tropics, which allows evaluating the support of geophysical methods and remote sensing in searching for missing persons. For projects, three experimental zones in Colombia used field forensic labs; here, the conditions were simulated, such as the graves found by the exhumation group of the Attorney General's Office. The simulated graves were filled with buried animals, human remains, and forensic objects of interest that would be commonly associated with discovered clandestine graves containing human remains.

4. Forensic Controlled Experimental Projects

The interest for doing contributions since the academy for searching missing people using technology in Colombia, begin with the proposal of a doctoral research carry out at the Universidad Nacional de Colombia and support for Universidad de Los Llanos, GeoSense, a Colombian private sector company, and Keele University in the UK from 2012 to

Fig. 3. Forensic controlled test site laboratories created to evaluate search methods to detect clandestine graves. a) Forensic Lab 1 at the Marengo Agricultural Center Universidad Nacional de Colombia in Bogotá Colombia (see [35]). b) Forensic Lab 2 at the Barcelona Experimental Farm, of the Universidad de Los Llanos in Villavicencio Colombia. c) Forensic Lab 3 at the Universidad Antonio Nariño in USME Campus, south of Bogota, Colombia (see [38]).

2016. [31]. As a result, human bone remains were used for geophysics research for the first time, and it was built the Forensic Laboratory 1 and 2. The experimental design constituted 12 graves at three depths in two different environments of Colombia to cover the most common conditions in which people have been found disappeared in Colombia [32–36].

Later, the research was continued by Universidad Antonio Nariño from Colombia, which has supported various related projects from 2018 until now, with the cooperation of Geosense, Universidad de Cundinamarca from Colombia Keele University in the UK. Finally, it should highlight that the American Academy of Forensic Science has funded the last project developed in 2020–2022, where the Forensic Laboratory 3 was built with six simulated graves using dismembered pig bodies, which sadly is another common burial scenario in Colombia [37–40].

5. Forensic Control Laboratory 1

The first forensic controlled laboratory research site is located at the Marengo Agricultural Center, Universidad Nacional de Colombia, at 2579 m above sea level (4°40'63'' N and 74°12'33'' W), located about 14 kilometers from the western highway that connects Bogotá with the municipality of Mosquera, department of Cundinamarca. It is situated in a rural area with a neotropical ecosystem of Bogotá savannah, with an average annual temperature of 14 °C and annual average rainfall of ~ 1124 mm with two dry and two rainy seasons. The study site has Andisol soil type with lacustrine sediments and volcanic ash mixed in.

In Laboratory 1, human and pig bodies and forensic objects of interest were buried in eight simulated graves with dimensions of 2 m wide by 2 m long [35]. Four burials were excavated to 0.8 m depth, and the other four to 1.2 m. Laboratory 1 is presented in Fig. 3(a), and the eight graves are described in Table 2.

6. Forensic Control Laboratory 2

The second forensic controlled laboratory research site is at the Barcelona Experimental Farm, of the Universidad de Los Llanos (4°04'47'' N and 73°35'17'' W), 391 m above sea level, located ~ 100 kilometers to the east of the highway that connects Bogotá with the municipality of Villavicencio, in the department of Meta. It is situated in a semi-rural tropical environment of the Eastern Plains, the study site has an average temperature of 27 °C and average annual rainfall of 3000 mm per year, with a dry period from December to March and a rainy season from April to November. The local geology corresponds to a Holocene alluvial terrace. The local soil type is an entisol with alluvial sediments, a mixture of fine-textured clay, and rounded rock fragments of different sizes.

Laboratory 2 has buried bodies and forensic objects of interest in four simulated graves with dimensions of 0,7 m wide by 1,7 m long. All burials were excavated to a depth of 0.5 m. Laboratory 2 is presented in Fig. 3(b), and the eight graves are described in Table 2.

Table 2
Description of Simulated Clandestine Graves in Forensic Laboratories 1 [35], 2 and 3 [38].

Tes Site	Grave	Dimensions	Contents	Test site	Dimensions	Grave
Lab 1	**A1/ A2**	(2 m x 2 m) x 0.8 m/ 1.2 m	freshly dispatched domestic pig cadavers - 70 kg	**Lab 2**	1.7 m x 0.7 m x 0.5 m	**A3**
	B1/ B2		Empty control.			**B3**
	C1/ C2		skeletonized human remains.			**C3**
	D1/ D2		beheaded and burnt skeletonized human remains.			**D3**

Place	Grave	Dimensions	Contents
Lab 3	**1**	(0,6 m x 0,6 m) x (0,5 m)	4 Pieces of Pig_2 with clothes, corresponding to head, 2 upper extremities, upper torso.
	2		3 Pieces of Pig_2; lower extremities and lower torso.
	3		Empty control
	4		4 Pieces of Pig_1 meatless with clothes, corresponding to head, 2 upper extremities, upper torso.
	5		3 Pieces of Pig_1; lower extremities and lower torso.
	6		Emplty control.

7. Forensic Controlled Laboratory 3

The third forensic controlled laboratory research site w is at the Universidad Antonio Nariño in USME Campus, 2270 m meters above sea level, south of Bogota, Colombia. The study site is in a semi-rural tropical environment with grass, trees, and near campus buildings. The site has an average temperature of 13 ºC and annual rainfall of 800 mm–1000 mm per year, with slightly seasonal variation. The local soil type is an upper ~15 cm thick clay-sandy loam with a more clay-dominated soil below this.

Laboratory 3 contains dismembered pig bodies and forensic objects of interest in six simulated graves with dimensions of 0.5 m wide by 0.5 m long, and 0.5 m depth [38]. Laboratory 3 is presented in Fig. 1(c), and the description of the grave on Fig. 3c and Table 2.

Various search methods supported by technologies were evaluated in the laboratories described above, focusing on the effectiveness of grave detection related to the environmental conditions and features of the areas under study.

8. Geophysical methods

Geophysical methods are based on measuring the physical properties of the subsoil materials and detecting contrasts between the causative bodies of interest and the environment surrounding them. Geophysical search methods, including Electrical Resistivity Tomography (ERT), Penetration Radar (GPR), and Magnetic Susceptibility, were applied to study Laboratories 1, 2, and 3. Additionally, in Laboratory 3, remote sensing techniques and mechanical soil resistance were also assessed. The geophysical techniques used for the projects and some results are now described.

9. Electrical resistivity tomography

Resistivity is a crucial electrical property of materials that depends on their capacity to allow or resist the passage of electric current. It is measured in the field to determine the presence of water, sediments, minerals, and rocks; for forensic purposes, it could indicate the presence or absence of illegal burials and dumps [40]. Electrical resistivity used in forensic studies can present two types of result: a vertical sounding, where depths at different strata can be interpolated (ERT-tomography), or a plan view of horizontal changes in resistivity [41].

Electrical resistivity, which is the inverse of the conductivity of materials, has been widely used in environmental forensic cases [42,43], in the detection of clandestine graves [44] in burials [45], and in controlled experiments [46–49]. However, the main environmental variables can affect the detection of the burials, including soil moisture, soil type and salinity [50,51].

ERT method was used to carry out the studies on Laboratory test sites 1, 2 and 3. The description of the data collection and results are presented.

9.1. ERT in forensic laboratory 1

Twenty-six separate field surveys were carried out in which eight simulated graves were monitored from 2013 to 2015 [35]. Ten resistivity measurements were made for each field surveyalong eight lines in an east-west direction, of which four separated by 0.50 m from each other crossed test graves A1, B1, C1, and D1; another four equally spaced crossed test graves A2, B2, C2, and D2. Each line was 17 m long, across which two electrodes moved 0.25 m apart. An Abem Terrameter geoelectric equipment was used for ERT data collection with A pole-pole array type, considered appropriate to detect horizontal variations in electrical resistivity [46,47].

Positive anomalies ranged from 68 Ω.m – 221 Ω.m, and negative anomalies ranged from 10 Ω.m – 29 Ω.m, corresponding to relative high and low resistivity anomalies with respect to background values. Results presented an adequate detection of all shallow graves over all time periods post-burial under study. Pig graves (A1 and A2) showed a high resistivity and the anomalies were more defined for shallow burials. Some results are presented in Fig. 2 for 52 weeks after burials.

9.2. ERT in forensic laboratory 2

Twenty-six separate field surveys were carried out in the same window time as Lab 1, in which the four simulated graves were monitored. The dataset was acquired with the same Geoelectric Abem Terrameter equipment under the conditions mentioned and using the good practice standard [43] as in Lab 1. Data was collected in an east-west direction through four lines parallel lines 11 m long, separated by 0.5 m and with data collection intervals every 0.25 m.

Positive anomalies ranged 403–2881 Ω.m, and negative anomalies ranged 226–851 Ω.m. There was a good ERT detection for all surveys during the study. The higher resistivities was observed over the skeletonized human remains graves and low resistivity for the pig graves. Some results are presented in Fig. 2, for 52 weeks after burials.

9.3. ERT in forensic laboratory 3

Thtee separate field surveys were carried out, unfortunately more could not be undertaken due to COVID19 fieldwork restrictions [38]. The dataset was acquired with a Geoelectric GeoAmp 303 equipment system, to measure the electric resistivity versus depth [38]. Three lines were located separated 0.2 m each from the next one to cover the survey area. The measures were taken crossing the simulated graves in a north-south direction and were carried out in parallel. The distance between the 32 electrodes along each line was 0.2 m.

Compared to control results acquired before the graves were built, post-burial datasets showed good results with positive resistivity anomalies over graves 1, 2, 4, and 5. The empty control grave was also well resolved. Even one year later, the four graves with parts of pigs and garments showed positive anomalies, although the anomaly positions related to graves 1 and 2 were a little displaced from the place they were built. Fig. 4 presents comparisons between ERT profiles 1 year after burials.

9.4. Ground Penetrating Radar (GPR)

Ground Penetrating Radar (GPR) is an electromagnetic method that uses the propagation and reflection of radio waves in a frequency range between 25 MHz and 1200 MHz emitted by a transmitting antenna from the surface to the subsoil; a receiving antenna reads the response of those electromagnetic pulses. The method permits the detection of forensic objects of interest. Therefore, GPR gives the forensic researcher information about the intensity, size, and general shape of the anomaly, which can be caused by human remains and artificially buried objects [41,52].

GPR is a geophysical method that has shown efficiency in searching for forensic evidence buried in the subsoil [52]. It is one of the most used geophysical equipment by judicial and police authorities worldwide for the search for evidence buried in the ground [46], since it presents one of the highest levels of resolution in surface geophysics methods. The GPR has been successful in numerous controlled experiments. Nevertheless, GPR has not been successful in locating graves in all conditions [53], for example in saline soils [47], wet clay [33,44] or wrongly utilised in certain situations [44].

GPR method was used to carry out studies in the controlled test site Laboratories 1,2, and 3. The description of the data collection and results is presented as follows.

9.5. GPR in forensic laboratory 1

The field surveys usedantenna frequencies of 250 MHz and 500 MHz and the same post-burial time interval as the ERT field surveys between 2013–2015. The surveys obtained 2D profiles used to generate 3D datasets. The 2D profiles show that simulated graves with pigs have been detected with strong reflection events during the study period. The control graves were not well resolved for any frequencies, only losing radar signal continuity over target positions. GPR poorly detected the graves with skeletons. GPR was losing signal radar continuity for beheaded and burnt remains graves. However the 3D datasets for all graves locations was depicted more clearly at 0.8 m depth. It is considered that these last results probably were determined by the disturbed soil in the graves, independent of the type of grave. A GPR profile example is shown in Fig. 3(a) that was surveyed 15 weeks after burial.

9.6. GPR in forensic laboratory 2

The field surveys used antenna frequencies 250 MHz and 500 MHz and the same post-burial time interval as the ERT field surveys between 2013–2015. All graves were detected very well. However, this study

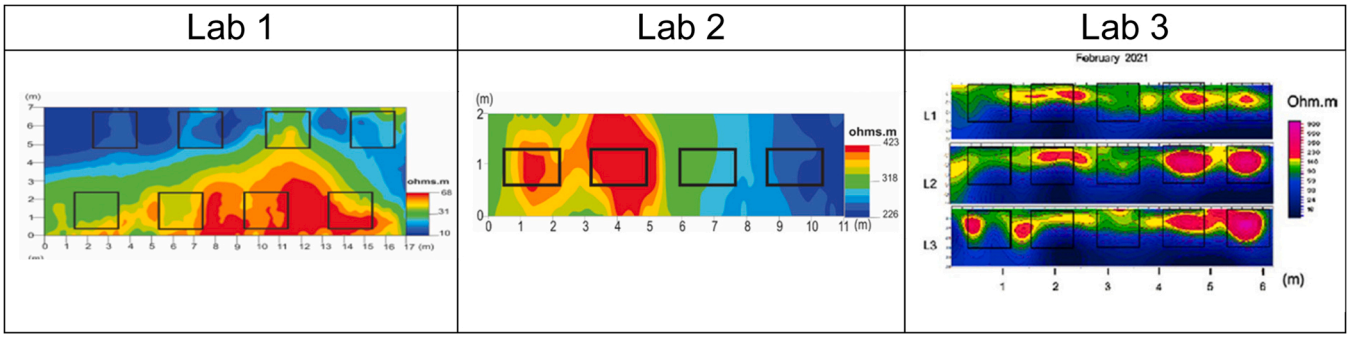

Fig. 4. Electrical Resistivity Tomography (ERT) 2D profiles showing examples from the Laboratories 1 [35], 2 and 3 [38]. Laboratoriy 3 data is 52 weeks after burial (from [38]).

interestingly shows that the pig grave had a hyperbolic reflection event, while the other graves showed more horizontal reflections during all the field surveys. A GPR 2D profile example is presented in Fig. 3(b) for 25 weeks after burial.

9.7. GPR in forensic lab 3

The field surveys used antenna frequencies 250 MHz, 500 MHz, and 800 MHz frequencies for 8, 36 and 56 weeks after burial. It was a promising result for 800 MHz, where positive anomalies were detected in five graves and partially in the other three graves. However, due to the pandemic situation caused by COVID 19, it was not possible to do more surveys. A GPR 2D profile example is presented in Fig. 3(c) for 294 weeks after burials.(Fig. 5).

10. Remote sensing

In scientific research, the remote sensing method was first used in Colombia to detect clandestine graves at controlled research facility test site laboratory 3 by an Unmanned aerial vehicle (UAV). Nevertheless, searches for clandestine burials start with large-scale methods, such as remote sensing [58], aerial and ultraviolet photography [55,56] and thermal imaging [57] before ground teams are employed. This technique collects information about an object or phenomenon without physically contacting the object. The UAV sensors work to collect radiation reflected by the entities or surrounding areas. The drone equipment for this research was a Parrot Bluegrass that integrated an RGB camera and a multispectral one. The RGB camera allows acquiring information on three visible spectral bands of red, blue, and green. On the other hand, it is possible to collect data from the not visible light spectrum with the multispectral camera, such as edge infrared and near-infrared [37,38].

The first flight before constructing the graves at Laboratory 3 was designated the Diagnostic Photogrammetric Flight. It permitted obtaining a detailed orthophoto of the experimental zone, a photo presentation that integrated the detailed features of aerial photo, and the geometric properties of a plane. The multispectral information also allows soil maps to cover the photosynthetic and phenological state of plants. It is more visible with the near-infrared and edge red wavelengths.

For data processing, it is possible to use the radiometric variables, which could give more contrast to the targets. As an example, NDVI or Normalized Difference Vegetation Index is an index that relates the spectral behavior between the near-infrared and the red band. It showed the photosynthetic activity in the zone. The green area shows high photosynthetic activity. Other radiometric indexes such as Green Normalized Difference Vegetation Index (GNDVI) and Green Coverage Index (GCI) were also obtained for this project. Some results are shown in Fig. 6. (a) presenting a multispectral image before the graves and (b) processing UAV data by the NDVI index, acquired 18 weeks after burials where the graves were well resolved.

11. Further geophysics methods

Magnetic susceptibility and mechanical resistance are physical properties that could also be useful in detecting graves. These have been considered in Labs 1, 2, and 3. The first magnitude is related to measuring the measure of a material susceptible to being magnetized [43]. Hence anomalies can be detected based on the differences in contrasts due to magnetic susceptibility measurements generating a low-intensity alternating current magnetic field, which produces changes in positive and negative susceptibilities [51] and data values are usually increased by combining magnetic minerals such as lodestone and artificial ferromagnetic materials [71]. Experiemnts over controlled research test site Laboratories 1 and 2 showed that it is possible to detect graves using this method, and that relatively shallow buried targets were better resolved than deeper ones. However, there were different degrees of target detection success, therefore it is necessary to continue applying this method to generate more completeknowledge [35].

The characterization of the mechanical properties of subsoil with the depth was developed inside and outside two graves in controlled research facilities test site Laboratory 1. It was obtained with Penetrologger equipment [54], where data about the overyling soils mechanical resistance to penetration is estimated. The preliminary results not shown here are promising due to a clear difference when there is or where there is no burial.

12. Case study

There was a terrible event during the armed conflict in Colombia in two towns of Casanare, a province located close to eastern cordillera, which resulted ~150 people to bedisappeared, that is a substantial number if it is considered that these are small towns comprise <3000 people. It was possible to support a subsequent search commission where ERT and UAV remote sensing datasets were collected in suspected burial places. ERT was the geophysical method selected due to the problematic access of the terrain (Fig. 7), which does not permit other technique s suchas GPR to be used. Nevertheless, it was still possible to obtain positive geophysical results. Animal bones were found in a suspected burial position which s demonstrated the efficiency of the ERT technique for grave detection, and anomalies detected could guide subsequent intrusive excavation work by the judicial entities. It was

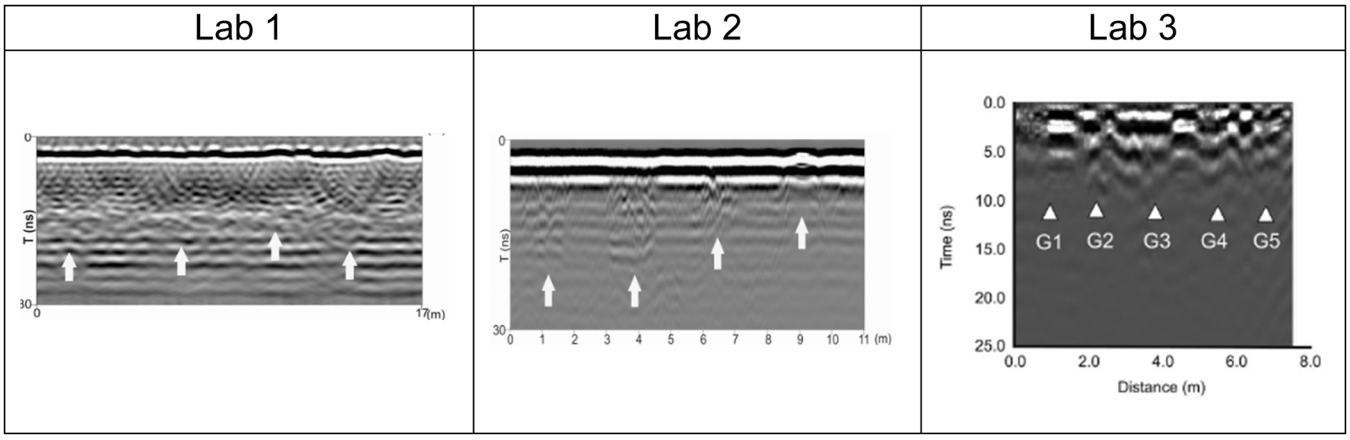

Fig. 5. GPR 2D profiles acquired over the Forensic Labs 1-3 controlled test research sites. a) GPR 2D profile scollected 46 weeks after burial (from [35]). b) GPR 2D profile collected 43 weeks after burial and c) GPR 2D profile collected 39 weeks after burial (from [38]). White arrows denote respective forensic targets of interest.

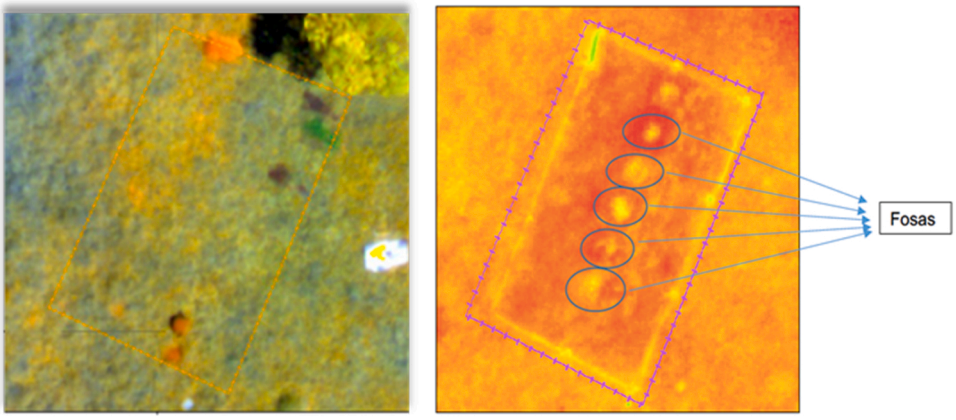

Fig. 6. Multispectral UAV data responses at controlled research test site Laboratory 3, (a) before and (b) 18 weeks after burial; the NDVI index was used to process the information where the graves are now well detected. Fosas = targets. Modified from [38].

Fig. 7. Using electrical resistivity tomography (ERT) in tropical terrain near Casanare to locate clandestine graves of diseappeared, difficult to access and irregular ground to collect datasets from.

interesting to use during the planning of fieldwork, but it was not easy to use for detection due to the forested landscape [36,37].

13. Conclusion

The thousands of people who are victims of forced disappearances, and those who are still missing in Colombia, reveals serious human rights violations. This issue has caused the victim families (with the support of different NGOs) to claim to the Government for the right to know the fate and whereabouts of their loved ones, all this in the context of truth, justice and reparation. Despite laws and decrees that have been developed, these are not enough for the resolution of all the crimes that have occurred through several decades in the 20th and 21st centuries.

The last peace agreement between the Colombian government and FARC-EP has generated spaces for reconciliation and approximation between victims and perpetrators. In addition, it has become the starting point for the clarification of the truth of human crimes that have marked the Colombian conflict.

As may be seen by the magnitude of the missing, the humanitarian challenge that Colombia faces, requires multidisciplinary scientific and technological knowledge in order to increase the success probability in the search and in the identification of the deceased; also decrease the time in the search for disappeared persons and the time for an answer to the families. Due to the geography that is quite extensive and complex in the country, the use of geosciences through remote sensors and geophysical equipment such as georadar and electrical tomography, could aid in locating potential grave positions of the diseappeared.

The aforementioned is part of the experimental knowledge that is being generated from academia, simulating graves in conditions in which the judicial police have found missing persons in all the country will aid the subsequent forensic searches of the diseappeared.

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References

[1] United Nations. Rome Statute of the International Criminal Court. Retrieved from ⟨https://www.ohchr.org/en/instruments-mechanisms/instruments/rome-statute-international-criminal-court⟩.
[2] Consejo de Redacción. Recuento histórico de la desaparición forzada en Colombia desde 1977 hasta 1988. Retrieved from ⟨https://consejoderedaccion.org/publicaciones/recuento-historico-de-la-desaparicion-forzada-en-colombia-desde-1977-hasta-1988⟩.
[3] Hacemos Memoria. ¿Por qué se dio el Estatuto de Seguridad? La Comisión busca respuestas. Retrieved from ⟨https://hacemosmemoria.org/2020/08/21/por-que-se-dio-el-estatuto-de-seguridad-la-comision-busca-respuestas/⟩.
[4] Comisión de la Verdad. La Comisión busca la verdad del Estatuto de Seguridad durante el gobierno de Julio César Turbay. Retrieved from ⟨https://comisiondelaverdad.co/actualidad/noticias/comision-busca-verdad-estatuto-seguridad-gobierno-julio-cesar-turbay⟩.
[5] C. Jiménez, El Estatuto de Seguridad, la aplicabilidad de la doctrina de la Seguridad Nacional en Colombia, Colección 20 (2009) 75–105. ISSN-e 1850-003X, Nº.
[6] ASFADDES. Asociación de familiares de detenidos desaparecidos. Retrieved from ⟨https://asfaddes.org/⟩.
[7] Comisión de la Verdad. Las cajas negras de la desaparición forzada. Retrieved from ⟨https://comisiondelaverdad.co/actualidad/noticias/las-cajas-negras-de-la-desaparicion-forzada⟩.

[8] Comisión Interamericana de Derechos Humanos. Technical Data: Rodríguez Vera y otros (Desaparecidos del Palacio de Justicia) Vs. Colombia. Retrieved from ⟨https://www.corteidh.or.cr/cf/Jurisprudencia2/ficha_tecnica.cfm?lang=en&nId_Ficha=461⟩.

[9] J. Vivas, C.H. Villegas, The Colombian experience in forensic human identification, in: R. Parra, S. Zapico, D. Ubelaker (Eds.), Forensic Science and Humanitarian Actions: Interacting with the Dead and the Living, John Wiley & Sons, 2020, pp. 693–702.

[10] Centro Nacional de Memoria Histórica. ¡Basta Ya! Colombia: Memoria de Guerra y Dignidad. Resumen. Bogotá: Pro-Off Set, 2013.

[11] M.C. Sanabria, H. Osorio, Ciencias forenses y antropología forense en el posconflicto colombiano, Rev. Crim. 57 (3) (2015) 119–134.

[12] Corte Constitucional. Sentencia No. C-574/92. Retrieved from ⟨https://www.corteconstitucional.gov.co/RELATORIA/1992/C-574–92.htm⟩.

[13] Diario Oficial No. 44.073, de 7 de julio de 2000. LEY 589 DE 2000. Retrieved from ⟨http://www.secretariasenado.gov.co/senado/basedoc/ley_0589_2000.html⟩.

[14] A. Tamayo, Missing Persons and Unidentified Human Remains: The Perspective from Armed Conflict Victims Exhumed in Granada, 317, Forensic Science International,, Colombia, 2020, 110529.

[15] Inter-American Convention on forced disappearance of persons. Retrieved from ⟨https://www.oas.org/juridico/english/treaties/a-60.html⟩.

[16] ⟨http://www.secretariasenado.gov.co/senado/basedoc/ley_0707_2001.html⟩,

[17] ⟨https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=19123⟩.

[18] ⟨https://www.corteconstitucional.gov.co/relatoria/2011/C-620–11.htm#:~:text=C%2D620%2D11%20Corte%20Constitucional%20de%20Colombia&text=Revisi%C3%B3n%20de%20constitucionalidad%20de%20la,20%20de%20diciembre%20de%202006⟩.

[19] ⟨https://www.pares.com.co/post/procesos-de-paz-en-colombia⟩.

[20] ⟨https://www.fiscalia.gov.co/colombia/wp-content/uploads/2013/04/Ley-975-del-25-de-julio-de-2005-concordada-con-decretos-y-sentencias-de-constitucionalidad.pdf⟩.

[21] Sistema Único de Información Normativa. Decreto 589 de 2017. Retrieved from ⟨https://www.suin-juriscol.gov.co/viewDocument.asp?ruta=Decretos/30030450⟩.

[22] ⟨https://www.cancilleria.gov.co/sites/default/files/Fotos2016/12.11_1.2016nuevoacuerdofinal.pdf⟩.

[23] ⟨https]://desaparicionforzada.com/unidad-de-busqueda-de-personas-dadas-por-desaparecidas-ubpd/⟩.

[24] ⟨https://www.medicinalegal.gov.co/rnd-registro-de-desaparecidos⟩.

[25] ⟨https://micrositios.centrodememoriahistorica.gov.co/observatorio/infografias/desaparicion-forzada/⟩.

[26] ⟨https://www.unidadvictimas.gov.co/es/registro-unico-de-victimas-ruv/37394⟩).

[27] International Committee of the Red Cross. 120,000 reasons to keep searching in Colombia: The missing persons. https://www.icrc.org/en/missi ng-persons-Colombia-IHLAccessed 13 July 2021.

[28] Centro Nacional de Memoria Histórica [CNMH], Hasta encontrarlos. El drama de la desaparición forzada en Colombia, Imprenta Nacional,, Bogotá, 2016.

[29] GRUBE, 2022. Consolidado de exhumaciones, reporte estadístico. Fiscalía General de la Nación. Retrieved from ⟨https://www.fiscalia.gov.co/colombia/wp-content/uploads/2022–04-30-reporte-grube.pdf⟩.

[30] A. Guzman, C. Sanabria, The origin and development of forensic anthropology and archaeology in Colombia, in: S. Soren Blau, D.H. Ubelaker (Eds.), Handbook of Forensic Anthropology and Archaeology, second ed., Routledge, 2018, pp. 75–93.

[31] Molina C.M. Metodología para la búsqueda de fosas a partir de la interpretación de anomalías en los datos obtenidos mediante la aplicación geofísica de alta resolución. Universidad Nacional de Colombia. Facultad de Ciencias. Departamento de Geociencias. Tesis Doctoral, 2016.

[32] C.M. Molina, O. Hernandez, J.K. Pringle, Experiments to detect clandestine graves from interpreted high resolution geophysical anomalies. Proceedings of the Meeting of Americas, AGU,, Cancun, México, 2013.

[33] C.M. Molina, J.K. Pringle, M. Saumett, O. Hernandez, Preliminary results of sequential monitoring of simulated clandestine graves in Colombia, South America, using ground penetrating radar and botany, Forensic Sci. Int 248 (2015) 61–70.

[34] C.M. Molina, J.K. Pringle, M. Saumett, G.T. Evans, Geophysical and botanical monitoring of simulated graves in a tropical rainforest, J. Environ. App. Geophys. 135 (2016) 232–242.

[35] C.M. Molina, J.K. Pringle, M. Saumett, G.T. Evans, Geophysical monitoring of simulated graves with resistivity, magnetic susceptibility, conductivity and GPR in Colombia, South America, J. Forensic Int. 261 (2016) 106–115.

[36] C.M. Molina, K.D. Wisniewski, J. Drake, A. Baena, A. Guatame, J.K. Pringle, Testing application of geographical information systems, forensic geomorphology and electrical resistivity tomography to investigate clandestine grave sites in Colombia, South America, J. Forensic Sci. 65 (1) (2020) 266–273 (Jan).

[37] Drake Jonathan, Molina Carlos Martín, Avila Edier Fernando, Baena Alejandra, Photogrammetry and electrical resistivity tomography for the investigation of the clandestine graves in Colombia, Photogramm. Eng. Remote Sens. 87 (2021) 597–604.

[38] C.M. Molina, K.D. Wisniewski, Heaton Vivienne, Pringle Jamie, Avila Edier Fernando, Herrera Luis Alberto, Guerrero Jorge, Saumett Miguel, Echeverry Raúl, Duarte Mario, Baena Alejandra, Monitoring of simulated clandestine graves of dismembered victims using UAVs, electrical tomography, and GPR over one year to aid investigations of human rights violations in Colombia, South America, J. Forensic Sci. 67 (3) (2021) 1060–1071 (Dic).

[39] Pringle, Jamie., Baena, Alejandra., Molina, C.M., Wisniewski, K.D., Heaton, Vivienne. The science that is helping researchers find the 'disappeared' in Latin America. The Conversation. 2022, April 5). Retrieved May 5, 2022, from ⟨https://theconversation.com/the-science-that-is-helping-researchers-find-the-disappeared-in-latin-america-174600⟩.

[40] A. Ruffeell, B. Kulsea, Application of geophysical techniques in identifying illegaly buried toxic waste, Environ. Forensics 10 (2009) 196–207.

[41] A. Ruffell, J. McKinley, Geoforensics, Willey Black, 2008.

[42] J.K. Pringle, A. Ruffell, J.R. Jervis, J.D. Donnelly, J. McKinley, J.D. Hansen, R. Morgan, D. Pirrie, M. Harrison, The use of geoscience methods for terrestrial forensic searches, Earth Sci. Rev. 114 (2012) 108–123.

[43] J.M. Reynolds, An Introduction to Applied and Environmental Geophysics, second ed., Wiley, 2011.

[44] J.K. Pringle, J.R. Jervis, Electrical resistivity survey to search for a recent clandestine burial of a homicide victim, UK, Forensic Sci. Int. 202 (2010) e1–e7.

[45] H.C. Dick, J.K. Pringle, B. Sloane, J. Carver, K.D. Wisniewski, A. Haffenden, S. Porter, D. Roberts, N.J. Cassidy, Detecting and characterising of Black Death burials by multiproxy geophysical methods, J. Arch. Sci. 59 (2015) 132–141.

[46] J.K. Pringle, A. Ruffell, J.R. Jervis, J.D. Donnelly, J. McKinley, J.D. Hansen, R. Morgan, D. Pirrie, M. Harrison, The use of geoscience methods for terrestrial forensic searches, Earth Sci. Rev. 114 (2012) 108–123.

[47] J.K. Pringle, C. Holland, K. Szkornik, M. Harrison, Establishing forensic search methodologies and geophysical surveying for the detection of clandestine graves in coastal beach environments, Forensic Sci. Int. 219 (2012) e29–e36.

[48] J.K. Pringle, J.R. Jervis, J.D. Hansen, N.J. Cassidy, G.M. Jones, J.P. Cassella, Geophysical monitoring of simulated clandestine graves using electrical and Ground Penetrating Radar methods: 0-3 years, J. Forensic Sci. 57 (2012) 1467–1486.

[49] J.K. Pringle, J.R. Jervis, J.P. Cassella, N.J. Cassidy, Time-lapse geophysical investigations over a simulated urban clandestine grave, J. Forensic Sci. 53 (2008) 1405–1417.

[50] J.R. Jervis, J.K. Pringle, A study of the effect of seasonal climatic factors on the electrical resistivity response of three experimental graves, J. Appl. Geophys 108 (2014) 53–60.

[51] J.D. Hansen, J.K. Pringle, J. Goodwin, GPR and bulk ground resistivity surveys in graveyards: locating unmarked burials in contrasting soil types, Forensic Sci. Int. 237 (2014) e14–e29.

[52] M. Beres, M. Luetscher, R. Olivier, Integration of ground-enetrating radar and microgravimetric methods to map shallow caves, J. Appl. Geophys. 46 (2001) 249–262.

[53] J. Milsom, A. Eriksen, Field Geophysics, second ed., Wiley, 2011.

[54] Penetrologger. Eijkelkamp. (n.d.). Retrieved May 6, 2022, from ⟨https://sp.eijkelkamp.com/productos/equipo-de-medici-n-de-campo/penetrologger-con-gps.html⟩.

[55] G.M. Brilis, R.J. van Waasbergen, P.M. Stokely, C.L. Gerlach, Remote sensing tools assist in environmental forensics: part II digital tools, Environ. Forensics 2 (3) (2001) 223–229, https://doi.org/10.1006/enfo.2000.0033.

[56] W.M. Grip, R.W. Grip, R.D. Morrison, Application of aerial photography and photogrammetry in environmental forensic investigations, Environ. Forensics 1 (3) (2000) 121–129, https://doi.org/10.1006/enfo.2000.0014.

[57] D.J. Dickinson, The aerial use of an infrared camera in a police search for the body of a missing person in New Zealand, J. Forensic Sci. Soc. 16 (3) (1976) 205–211, https://doi.org/10.1016/S0015-7368(76)71062-4.

[58] H. Brabazon, J.M. DeBruyn, S.C. Lenaghan, F. Li, A.Z. Mundorff, D.W. Steadman, C. N. Stewart Jr., Plants to remotely detect human decomposition? Trends Plant Sci. 25 (10) (2020) 947–949, https://doi.org/10.1016/j.tplants.2020.07.013.