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GIS-BASED RAG-CODED SEARCH PRIORITY SCENARIOS FOR PREDICTIVE MAPS TO PREVENT FUTURE SERIAL SERIOUS CRIMES: THE CASE STUDY OF THE FLORENCE MONSTER

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ABSTRACT. In the present research, the GIS (Geographical Information System)-based RAG (Red-Amber-Green) color-coded search priority system was applied to the case study of the serial murders of the monster of Florence occurred between 1968 and 1985 in the Florence province (northern Italy). Through a predictive search priority *scenario*, the RAG maps were aimed to identify the possible areas where the monster could have hypothetically continued to hit if still alive. The identified Red-code area allowed to obtain a very useful result, reducing to the 21% the extension of the site where the serial killer had to continue to hit. In predictive terms, this method, if applied at that epoch, could have helped law enforcements and the judicial authority to strongly reduce the areas to monitor for arresting the responsible of these tremendous murderers.

1. Introduction

Most serial killers (SKs) are psychopathic subjects living with unstoppable homicidal impulses (Jaspers 1913; P. J. Brantingham and P. L. Brantingham 1981; Kernberg 1984; Douglas 1992; Bruno 1994, 1995; Fornari 1995; Jones 1996; Bruno and Marrazzi 2000; De Pasquali 2001; S. T. Holmes and R. M. Holmes 2002; FBI Behavioral Analysis Unit-2 National Center for the Analysis of Violent Crime Critical Incident Response Group 2005; Douglas *et al.* 2006; Schneider 2008; Bruno *et al.* 2010; Häfner 2011; Baron-Cohen 2012; Hare 2018). To capture SKs and stop their serial murders may be a very arduous task for police forces and judicial authority. This depends on the fact that most SKs appear as unsuspected people well integrated in the society because they wear a "mask" (Cleckley 1941), being as wolves disguised by “innocent lambs”. In criminal investigations regarding serial murders occurred outdoor in the countryside, the contribute of forensic geologists may be crucial in assisting police forces and other forensic experts (coroners, criminal psychologists, and psychiatrics; P. J. Brantingham and P. L. Brantingham 1981). In such circumstances, the victims and the SKs may interact with the surrounding environment, made up of sediments, soils, water, insects, and plants. This human-environment interactions may be responsible for a transfer of biotic and abiotic materials from the scenes of events to the actors of serial crimes. A team composed of forensic geologists, geographers,

palaeontologists, taphonomists, entomologists, botanists, ecologists, and engineers, may provide very useful data, being specialist in the knowledge of the territory and ecosystems. The involvement of different expertise skills, increasingly appearing in the Forensic Science Italian *panorama*, may strongly contribute to investigation, as demonstrated by the solved case works reported by experts in the last decades (Lombardi 1999; Di Maggio *et al.* 2013; Caccianiga *et al.* 2021; Giordani *et al.* 2023; Marra 2023; Marra, Di Silvestro, and Somma 2023; Morabito, Mondello, and Somma 2023; Morabito and Somma 2023; Somma 2023a,b,c; Somma *et al.* 2023a,c; Somma and Maniscalco 2023). Moreover, a multidisciplinary approach to the crime scene, linking criminalistics to criminology (Ponti 1990; Ponti and Fornari 1995; Ponti and Merzagora Betsos 2008; Picozzi and Intini 2009) with criminal and geographic profilers, may be of paramount importance in outdoor crime scenes where serial crimes occurred. Geographical factors may be crucial in influencing the mental map and criminal behaviour of serial concealers and murderers, as recently reported in research related to corpse concealments (Somma *et al.* 2018; Somma and Costa 2022; Berezowski *et al.* 2023). Criminal behaviours may be influenced by the geography of the places as stated by the environmental and investigative psychologists working on the topic of the Geographical Profiling (GP), a branch of the criminology applied for assisting police in limiting the number of suspects among hundreds of people, by searching for the possible home/base of the SKs of marauder type (Canter 2009). SKs carefully plan their illicit actions, searching for places provided of specific territorial and geographical features, that are significative in their minds. Recent research was devoted to Geographical Information System (GIS)-based applications, implemented for assisting investigations in the search for illicit gravesites (France *et al.* 1997; Ruffell and Wilson 1998; Ruffell 2004, 2005; Manhein, Listi, and Leitner 2006; Salsarola and Cattaneo 2009; Harrison 2011; Larson, Vass, and Wise 2011; Pringle *et al.* 2012; Donnelly and Harrison 2013; Ruffell *et al.* 2017; Sagripanti *et al.* 2017; López Batista, Rodríguez López, and Fieguth Batista 2018; Somma *et al.* 2018; Rocke, Ruffell, and Donnelly 2021; Rocke and Ruffell 2022; Somma 2022a), recently validated on real crime scenes (Somma and Costa 2022). One of the major criticisms of this previous research was the subjective character used for limiting the search area.

With this in mind, a more advanced multidisciplinary approach, based on principles of both Forensic Geology, GIS systems, and Geographical Profiling (GP), was used for furtherly implement the GIS-based method of Somma *et al.* (2018) and Somma and Costa (2022). The present paper illustrates the results of an integrated GP and geomatic study dedicated to the reconstruction of a GIS-based RAG (Red-Amber-Green) color-coded search priority system, based on a specific geological conceptual model, applied to the serial murders committed by the monster of Florence, occurred between 1968 and 1985 in the Florence province (northern Italy) (Somma 2023b). Principles and methods of Forensic Geology, GIS technology, and GP were aimed to identify possible dangerous areas where the monster could hypothetically continue to hit, in the hypothesis he was still alive nowadays. With this purpose, predictive search priority RAG *scenarios*, based on a territorial conceptual model, were planned and designed for a simulated case, foreseeing a hypothesis of prevention strategy with the consequent criminalistic and criminological consequences, and implications for assisting police forces and judicial authority.

2. Methods

Forensic Geology (known also as Forensic Geosciences or Geoforensics) applies principles, techniques, and methods of the Earth Sciences for the solution of criminal cases (Murray and Tedrow 1975; Palenik 1982; Tindall 1994; Lombardi 1999; Bull *et al.* 2004; Murray 2004a,b; Pye and Croft 2004; Pye 2005; Ruffell and McKinley 2005; McKinley and Ruffell 2007; Morgan and Bull 2007; Pye 2007; Ruffell and McKinley 2008; Fitzpatrick, Raven, and Forrester 2009; Pirrie 2009; Ruffell 2010; Di Maggio *et al.* 2013; Ruffell and McKinley 2014; Pirrie, Dawson, and Graham 2017; Donnelly *et al.* 2021; Fitzpatrick and Donnelly 2021; Spoto, Somma, and Crea 2021; Somma 2022a; Somma *et al.* 2023d; Spoto 2023; Spoto, Barone, and Somma 2023; Tagliabue *et al.* 2023a,b). This branch of criminalistics may be applied to the criminal investigation and crime scene "crystallization" (Baldino *et al.* 2023; Somma *et al.* 2023a,b,c) related to most serious crimes, such as homicides, corpse concealment, and kidnappings, for assisting police forces, judicial authority, and lawyers. The geological features investigated may be related to minerals, rocks, fossils, and the territory/landscapes in general (geological evidence). Among the geosciences, the application of remote sensing is very useful being an approach for studying the territory from remote during preliminary studies or for accessing at distance dangerous or inaccessible sites (Davenport 2001; Ruffell 2002). The GIS technology allows to upload big data linked to the territorial features, georeferencing them in the space, and to manage them for further treatment of the spatial data (Herrmann and Devlin 2008; Ruffell and McKinley 2008; Wolff and Asche 2009; Pringle and Jervis 2010; Elmes, Roedl, and Conley 2014; Bunch, Kim, and Brunelli 2017). The GIS technology allows to plan geographical models designed on specific conceptual models developed by the expert on the base of the finality of the research. In the cases of serial murders, the first fundamental step in the planning of predictive search priority RAG *scenarios* consists in the identification of the main environmental/territorial control factors that presumably influence the offender's mental map in the choice of the site of his/her interest (the target) (Somma *et al.* 2018; Somma and Costa 2022). These significant factors influencing the perpetrator had to be searched, recognized, and identified during judicial inspections and documental analyses. The identification of these control factors is strictly depending on the carefully observation of all the details and characteristics associated with the different crime scenes. These features, if repetitive in all the scenes, may be selected as possible control factors influencing the SK's behaviour. These factors may be mostly subjective and strictly depending on the personal past of the offender and his/her psychological disease or mental hillness. The identified environmental/territorial control factors had to be evaluated for being considered possible elements of the model. The more peculiar is the factor, the higher is the possibility that this factor is decisive in the mental map of the offender. The peculiarity together with the repeatability of the occurrence of the factors recognized in each target area of the same criminal series, make them valid candidates for being considered in the conceptual model. Some examples of environmental/territorial control factors influencing the SKs in the choice of a crime scene might be dark, isolated, parking sites in rural areas or the covert effect of vegetation. On the base of a functional and effective model, responding to precise criminalistic and criminological conditions, the planning of RAG maps of each factor may be carried out, for reconstructing the search priority *scenarios* related to the

specific target (future crime scene, burial site). Search *scenarios* are obtained by crossing the geographical and environmental information reported in each RAG map of the individuated environmental/territorial control factors (Figure 1). A crucial element to consider in the GIS model is related to the method used for defining the extension of the search area. In the previous GIS-based models proposed by geologists (Somma *et al.* 2018; Somma and Costa 2022), the choice of the limit of the search area was based only on subjective *criteria*. A providential contribution for solving this criticism, still evident to the authors, derived from the research accomplished by the investigative psychologist David Canter, who was responsible for individuating the so-called criminal sphere, one of the cornerstones on which the Geographical Profiling is based (Canter and Heritage 1990; Canter and Larkin 1993; Canter and Gregory 1994; Canter 1995a,b; Canter and Fritzon 1998; Canter, Hughes, and Kirby 1998; Canter and Snook 1999; Canter *et al.* 2000; Canter and Hodge 2000; Rossmo 2000; Canter 2003; Canter and Youngs 2003; Canter and Hammond 2006, 2007; Aldershot, Canter, and Youngs 2008; Canter and Shalev 2008; Canter 2009; Canter and Youngs 2009; Berezowski *et al.* 2023). In a serial crime, most of SKs are marauder, *i.e.* subjects that after the crime return immediately at their home/base. In such circumstances, the criminal sphere (or circle) may be defined as the space (or area) of criminal action of the serial offender. The diameter of the circle may be individuated in the line linking the most distant sites where the offenders killed. According to the research on the GP, the marauder SKs (86% of the American offenders are marauder, Hodge and Canter 1998) usually kill and live within the criminal circle. This concept of paramount importance for his criminalistic and criminological implications contributed greatly to localize the home/base of the serial offenders. The criminal circle was used in the present GIS model to define the search limit implementing it for a better prioritization of the target areas. Based on the above, the here presented predictive search priority RAG *scenario* was reconstructed firstly defining the conceptual model based on the control factors. Secondly, the RAG color codes related to each control factor were assigned to each point of the RAG maps. Red and Green codes were assigned for each point, presenting or not presenting, respectively, the specific control factor predisposing the site to be a crime scene or a site for illicit activities. Amber code was attributed for the points with intermediate features among the Red and Green coded areas. For example, if a site is dark, the Red code may be assigned, being suitable for being a potential crime scene, whereas if a site is well illuminated, the Green code may be considered, being a site potentially not suitable for serial crimes. In other terms, the Red and Green colors indicate the different values of the risk for the public safety and security, *i.e.* high or low, respectively. The RAG color codes, reported in all the RAG map layers of the factors, were finally crossed in the GIS system, in order to obtain the RAG map priority search *scenarios* (Figure 1) for the searched target area. Each point of the search *scenario* was assigned to a:

i Red-code obtained crossing Red-codes of the control factors;
ii Amber-code obtained crossing Amber-codes, or Red- and Amber-codes of the control factors;
iii Green-code obtained crossing Green-codes, or Red-, Amber-, and Green-codes of the control factors.

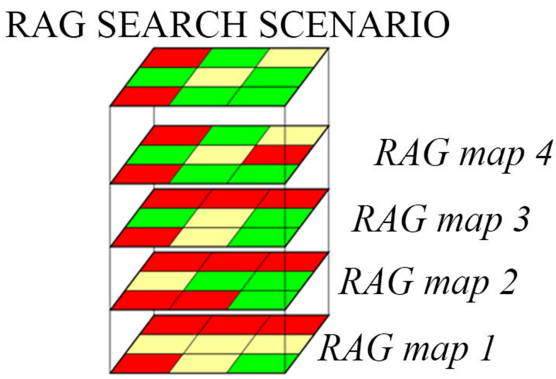

FIGURE 1. Scheme of the conceptual model used for constructing the RAG priority search *scenario*, crossing geographical information from four different GIS RAG maps (1-4) related to the selected environmental/territorial factors of control. To each area of the RAG map, a RAG-coded color was assigned. The RAG-coded colors of the priority search *scenario* (upper map) were obtained by crossing the RAG-coded colors of each one of the four RAG maps, through GIS tools.

3. Case study

It is noteworthy that lust murderers are SKs that may commit necrophiliac sexual killings accompanied by excisions of sexual organs, rituals, and staging. A case of lust murders occurred in in the province of Florence (Northern Italy) between the 22 August 1968 and 9 August 1985[1] (Table 1). This SK was denominated by journalists "monster of Florence" on the base of the geographic region in which the SK committed the murders. The monster of Florence was active during about 17 years of criminal activity. The series of these heinous eight double homicides (Table 1), linked together, took place in the Florentine countryside (De Fazio, Galliani, and Luberto 1984; De Fazio *et al.* 1985; Dunn *et al.* 1989; Perugini 1994; Giuttari 2022; Scaffidi 2022; Somma 2022b). The SK killed couples seeking for intimacy, generally secluded in a car. Despite the brutality of the crimes, few physical evidence were collected at crime scenes. The only immaterial traces left by the killer on the scenes were ascribable to the selection of the sites, being characterized by certain features such as to be located in isolated and rural areas or other characteristics individuated by the authors in the present research.

[1] https://www.mostrodifirenze.com/ (Accessed online 20 January 2023)

TABLE 1. Date of the serial murders and names of the victims.

ID NUMBER	HOMICIDE DATE	COUPLE COMPONENT 1	COUPLE COMPONENT 2
1	22.08.1968	A.L.B.	B.L.
2	14.09.1974	P.G.	S.P.
3	06.06.1981	G.F.	C.D.N.
4	22.10.1981	S. B.	S.C.
5	19.06.1982	P.M.	A.M.
6	09.09.1983	W.F.H.M.	J.U.R.
7	29.07.1984	C.S.	P.G.R.
8	08.09.1985	J.M.K.	N.J.G.M.

3.1. GIS-based RAG maps and search *scenario*. The target areas of the GIS-based RAG priority search *scenario* consisted of the places where the probability that the monster of Florence could hit nowadays was high (Red coded area) in the hypothesis that the killer and the related partners were still alive. The possible environmental/territorial control factors of the eight crime scenes were deduced firstly on the base of a careful examination of the scenes together with the study of the rich investigative dossier and criminalistic and criminological documentation available[2] (De Fazio, Galliani, and Luberto 1984; De Fazio *et al.* 1985; Dunn *et al.* 1989; Perugini 1994; Giuttari 2022; Somma 2022b). Secondly, most of the sites were also surveyed in the field by one of the authors (R.S.) during several inspections of the places made during 2022. The comparison of the photographic record of the time with the current appearance suggested that most of the sites retained the same appereance. The results of this investigation allowed to verify as all the crime scenes were localized in hilly landscapes under 300 m of elevation (Table 2), in secluded places away from city centres (Table 2) and near the terminal parts of secondary roads (Table 2), in the proximity of the municipal limits (Table 2). All crimes occurred during the night in localities devoid of public lighting (Table 2). Four of these control factors were introduced in GIS-based RAG map layers, assigning to each point of the investigated area a RAG-color code depending on the assumption that the site was suitable or not of being a possible crime scene. A Red coded color was assigned to the sites at elevation lower than 300 m, being suitable for being potential crime scenes, whereas if a site was at elevation higher than 300 m, the Green code was assigned, being a site potentially not suitable for serial crimes (Table 3, Figures 2, 3a). A Red coded color was assigned to the sites near secondary and terminal roads, being suitable as potential crime scenes, whereas if a site was at a certain distance from these secondary roads, the Green code was assigned, being a site potentially not suitable for serial crimes (Table 3, Figures 2, 3b).

[2]https://www.youtube.com/watch?v=rPEO6xCjKyk/ (Accessed online 20 January 2023).

TABLE 2. Environmental/territorial control factors identified in each crime scene and used for the construction of the conceptual model of Figure 1.

Env./territorial control factors	**Description**
Elevation	Geographical areas comprised between a few tens of meters up to a maximum of 300 m of altitude above sea level (Table 3).
Roads	Places near secondary and terminal roads (Table 3).
Urban Planning	Rural areas away from city centres (Table 3).
Municipal Limits	Places near the municipal limits (Table 3).
Lighting Fixtures	Dark areas without lighting fixtures.

A Red coded color was assigned to the sites near the municipal limits, being suitable for being potential crime scenes, whereas if a site was at a certain distance from these limits, the Green code was assigned, being a site potentially not suitable for serial crimes (Table 3, Figures 2, 3c). Among the four factors considered in the model, the percentages of the factors Elevation and Municipal Limits appeared as the most peculiar geographical characteristics observed (Table 3, Figures 2, 3d). The RAG maps of the environmental/territorial control factors showed extents of the R-code areas comprised between 55 and 83% (Table 3, Figure 2). The merging of the GIS data related to the RAG maps of the environmental/territorial control factors produced the search priority *scenario* for future aggressions reported in Figure 4. The free and open source GIS software used was QGIS.

TABLE 3. RAG values for each RAG map of the environmental/territorial control factors.

Environmental/territorial control factors	**R (%)**	**A (%)**	**G (%)**
Elevation	65	13	22
Roads	74	6	19
Urban Planning	83	4	13
Municipal Limits	55	2	43

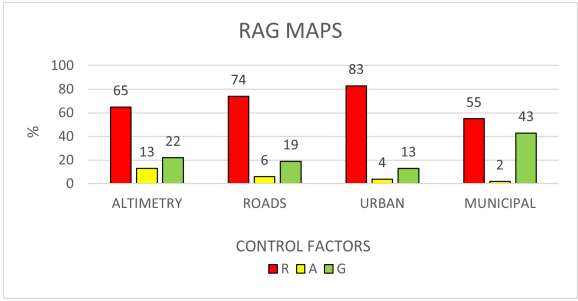

FIGURE 2. Histograms of the RAG maps of the environmental/territorial control factors.

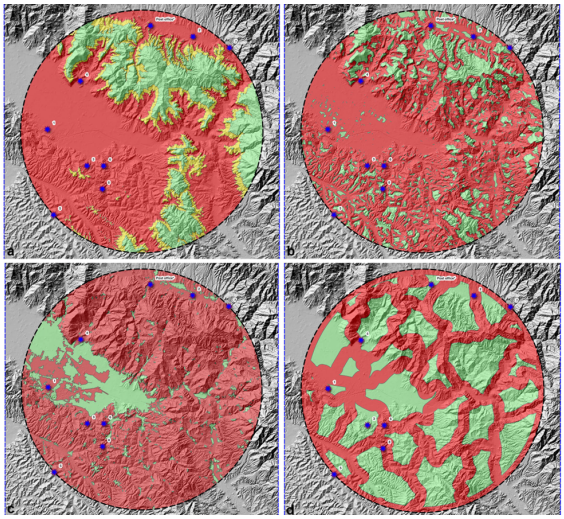

FIGURE 3. Serial crimes of the Florence Monster: RAG maps of the environmental/territorial control factors, delimited by the criminal circle (circle diameter = 44 km). The crime scenes are represented by a violet star with ID 1-8 numbers (reported in Table 1). a) Elevation RAG map, b) Roads RAG map, c) Urban Planning RAG map, d) Municipal Limits RAG map.

4. Discussion and conclusions

The Red values reported in each single RAG map of the environmental/territorial control factors did not reveal significant in terms of risk management (Table 3, Figures 2, 3). Differently, the GIS merging of the four RAG maps of the considered environmental/territorial control factors allowed to produce significative results, being the R-coded areas (Figure 4) reduced to 21% (Figure 5).

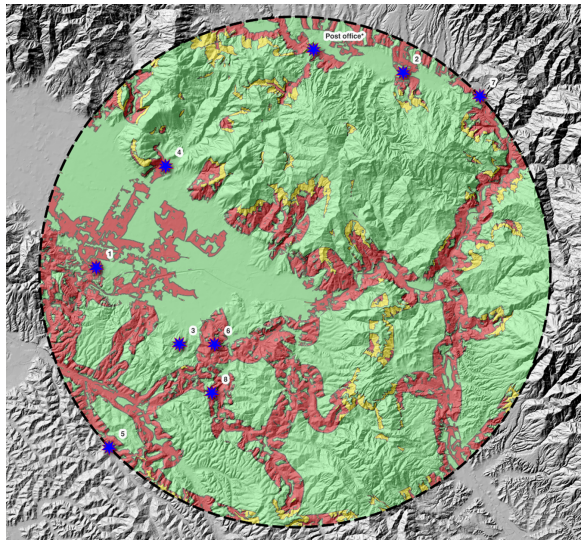

FIGURE 4. Search priority *scenario* for future aggressions (R=21%, A=10%, G=69%). The criminal circle has a diameter of 44 km. The crime scenes 1968-1985 are represented by a violet star with ID 1-8 numbers (reported in Table 1).

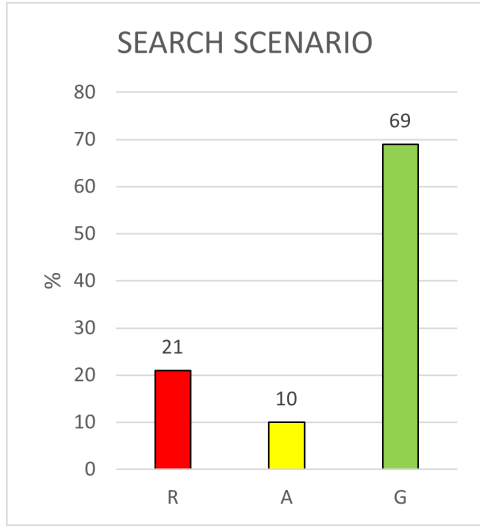

FIGURE 5. RAG values of the search priority *scenario*.

Even more significative results were obtained in previous experimental sites (Somma *et al.* 2018) and real crime scene (Somma and Costa 2022), in the planning of RAG priority search *scenarios* for clandestine graves (Byrd and Sutton 2023; Somma, Sutton, and Byrd 2023).

In such cases, the more elevated number of control factors, six, allowed to reduce the high priority search area extensions between 2 and 6. More elevated is the number of the environmental/territorial control factors and more elevated is the possibility to reduce the search target areas of interest. The method applied in the present paper was able to obtain a very useful result, strongly reducing the extension of the site at high priority (R) where the SK had to continue to hit, if still alive. In predictive terms, this method, if applied at that epoch of the facts, could have helped to strongly reduce the areas to be monitored by law enforcements for controlling the territory and arresting the responsible of these tremendous murders.

Author Contributions

Conceptualization, R.S.; methodology, R.S.; software, N.C.; validation, R.S. and N.C.; formal analysis, R.S. and N.C.; investigation, R.S.; resources, R.S.; data curation, R.S. and N.C.; writing original draft preparation, R.S.; writing review and editing, R.S.; visualization, R.S.; supervision, R.S. All authors have read and agreed to the published version of the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

The present research was initially developed during the thesis of the master' degree in Forensic Sciences of one of the Authors (R.S.) at the La Sapienza University of Rome (Tutor: Prof. Natale Fusaro) (Somma 2022b).

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