Preliminary communication

SPATIAL ANALYSIS AND IDENTIFICATION OF SUITABLE LANDING ZONES FOR AERIAL EVACUATION FROM THE CONGESTED URBAN AREAS

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Abstract: *According to the latest estimates (2023), slightly less than half of the population of Bosnia and Herzegovina (BH) lives within an urban area. Considering congested or inadequate road communications in the city centers, steep bounding relief as well as other potential obstacles, the issue of urgent evacuation becomes problematic, especially in an emergency. Using a composite model of BH urban zones with a high level of risk of natural disasters and/or incidents caused by the human factor, the goal is to outline the potential zones from which it is possible to organize and carry out the air evacuation of the endangered population. Upon evaluating causes and potential epicenters of disasters (earthquake, flood, industrial incident, terrorism), population density, road infrastructure, geomorphological and other features of the terrain, we selected potential air-evacuation nodes. The selection was based on two elements: 1. a semi-quantitative automated model that analyzes the available geospatial data (e.g. population, proximity to the epicenter, terrain coverage) and combined result of acceptability for the landing site and 2. qualitative-expert evaluation of selected landing sites by the pilots qualified and trained for urban search and rescue. The results of the two-tiered analysis suggest that the urban areas have at least three ideal locations and five acceptable locations for the sizable aerial evacuation of citizens in an emergency. The choice of locations and their sustainability depends on the type of potential disaster, but according to the available data, it is realistic to expect that the selected locations would withstand and remain partially usable in the majority of predicted extraordinary circumstances.*

Keywords: *Evacuation, Landing zone, Urban area, Disaster, Spatial analysis*

1. INTRODUCTION

According to the latest estimates (conclusive with 2023), about half of the Bosnia and Herzegovina (BH) population lives within a concentrated urban area (CEIC, 2023). Considering congested, dilapidated and non-contiguous road communications in the urban areas, unfavorable steep relief and other potential obstacles, the issue of urgent evacuation becomes problematic, especially in the case of a widespread emergency. Using the municipal areas of Sarajevo and Banja Luka as the sites with a high level of risk for natural disasters (earthquakes, flooding) and/or incidents caused by the human factor (aging energy infrastructure, war damage, natural hazards triggering technological accidents (i.e. (Paba & Cruz, 2021), neglect of the former industrial facilities), we have attempted to identify the potential zones from which it would be possible to organize and carry out the aerial evacuation of the affected population on a larger scale than previously analyzed (Smailbegovic & Mahmutovic, 2024).

2. METHODOLOGY

Evaluating the potential causes and epicenters of disasters (earthquake, flood, industrial incidents, terrorism), population density, road infrastructure, geomorphological and other terrain and land cover elements, we made a selection of potential (and possible) aerial evacuation points from the congested urban areas (Erskine et al. 2022). The analysis consisted of two elements: 1. a semi-quantitative automated, integrative spatial-matching model that analyzes the available geospatial data (e.g. population, proximity to the epicenter, terrain coverage) and assigns an overall suitability score for the particular landing site (i.e. Walter and Fritsch, 1999; Mertova, 2021) and 2. qualitative-expert evaluation of selected landing sites by the pilots qualified and trained for evacuation from such complex areas (Scherer at al. 2010). The qualitative assessment mimicked that of a pre-flight operational planning using a 1:25,000 scale map, digital terrain model and oblique imagery indicating any potential obstacles. The three (3) pilots tasked with assessment (post-brief interview), have been given the same datasets with the choice of potential LZ and asked to categorize them on the basis of available information and their past experience.

The main objective was to filter the various levels of geospatial data using the automated method and qualify or disqualify the potential sites by its overall matching score (i.e. open space, obstructions, accessibility, spatial correlation). The qualified areas were then fine-tuned and evaluated by expert pilots and assessed upon available data, experience and suitability of sustaining the evacuation operations with the available equipment.

2.1. SEMI QUANTITATIVE MODEL

The source of the data used in the semi-quantitative model is derived from the Open Geospatial Consortium compliant geospatial data, geared towards public-safety applications and interoperability (Reed, and Harne, 2015) and is sourced from the following online portals *Openstreetmap.org, openinframap.org* (for overhead powerlines and other obstructing infrastructure) *katastar.ba* (Federation of Bosnia and Herzegovina entity)*, rgurs.org* (Republic of Srpska entity), *preglednik.ippfbih.gov.ba* (Geospatial layers of the Federation of Bosnia and Herzegovina entity) and proprietary (author collected) d-GPS elevation data within the urban area of the City of Sarajevo. The weighing score and correlation matrices used in the data ranking and analysis are presented in Table 1 below.

Table 1: Geospatial layers

Layer type	Details	Score	Hazard	Correlated with:
Obstructions	Towers, Windmills	-3	High	Infrastructure, overhead
Relief	Hills, knolls, flats	2	Low	Open spaces
Infrastructure, overhead	Cables, powerlines	-4	High	Obstructions
Infrastructure, surface	Roads, rails	2	Low	Relief, open Spaces
Hydrography	Lake, river, wetland	-1	Medium	Surface cover
Surface cover	Field, Urban	2	Low	Infrastructure, hydrogr.
Open spaces	Park, Stadium, Field, Parking,	2	Very Low	Known landings, infrastructure,
Known hazards	Landslides, faults	-2	Med Hi	Obstructions
Known landing zones	Designated fields	3	NONE	NONE
No data tile	No available data	1	NONE	NONE

The datasets (rasters and point / vector data) are spatially correlated and fenced to the appropriate urban areas (Tuzla, Banja Luka, Sarajevo, Mostar) with the appropriate weights assigned to the grids covering the entire area of analysis. Because some layers tend to extend beyond the fenced region, it is essential that every non-computing raster value is converted to a numeric value (i.e. 1) and that the weight in its blank region be set to zero. The operations are often conducted with *Con* and *IsNull* operations. The weighted score is then computed using the layer correlation using:

$$(([\text{Layer A}] * \text{weight X}) + ([\text{Layer B}] * \text{weight Y})) / \Sigma \text{ weights})$$

Having assigned numeric value to the sum of the [layer]*[weight] values divided by the sum (Σ) of the [weight] values, each raster layer now contributes a nonzero value only where it has pertinent data. The final value in each cell should have a weighted and correlated mean of the pertinent rasters / layers that have values for that cell and fit within the boundaries of the other layers.

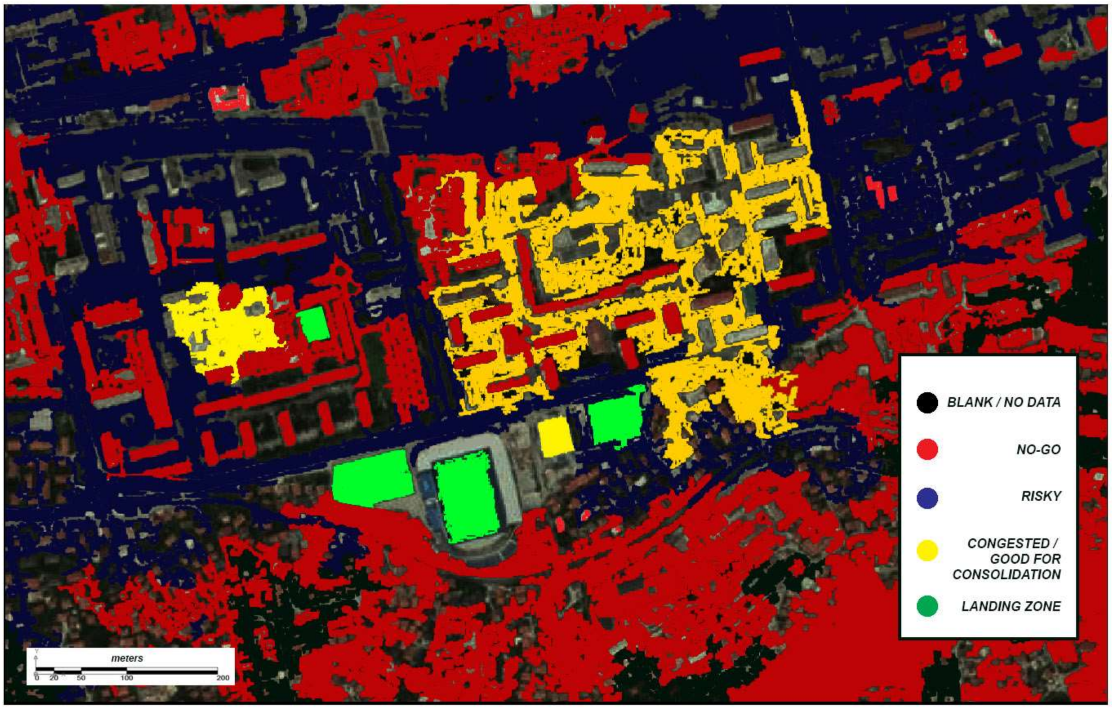

Figure 1: Example of resulting correlated and weighed risk model superposed on 2022 Orthophoto base of Sarajevo. Note suitable areas for landing zones outlined in green (two stadiums and two fields).

The example shown in Figure 1 outlines the portion of the model developed for Sarajevo, municipality of Novo Sarajevo which outlines four potential landing zones (green) that could accommodate suitable vertical air-transport as well as yellow areas, which may not be suitable for landing but present a potential zone for concentrating affected populace and assigning them to the appropriate evacuation zone. Red, blue and black areas are generally considered a “no-go” areas due to the lack of data, overhead obstructions, buildings and other factors that could affect the success of the evacuation operations.

It is important to note that while the model is scalable (remains coherent down to 1:1000 scale, as shown on Figure 2). It has difficulties accounting for the ephemeral details in the scene (i.e. cars, traffic, vegetation, standing water) that may be present in an urban area and present a considerable risk in the evacuation operations.

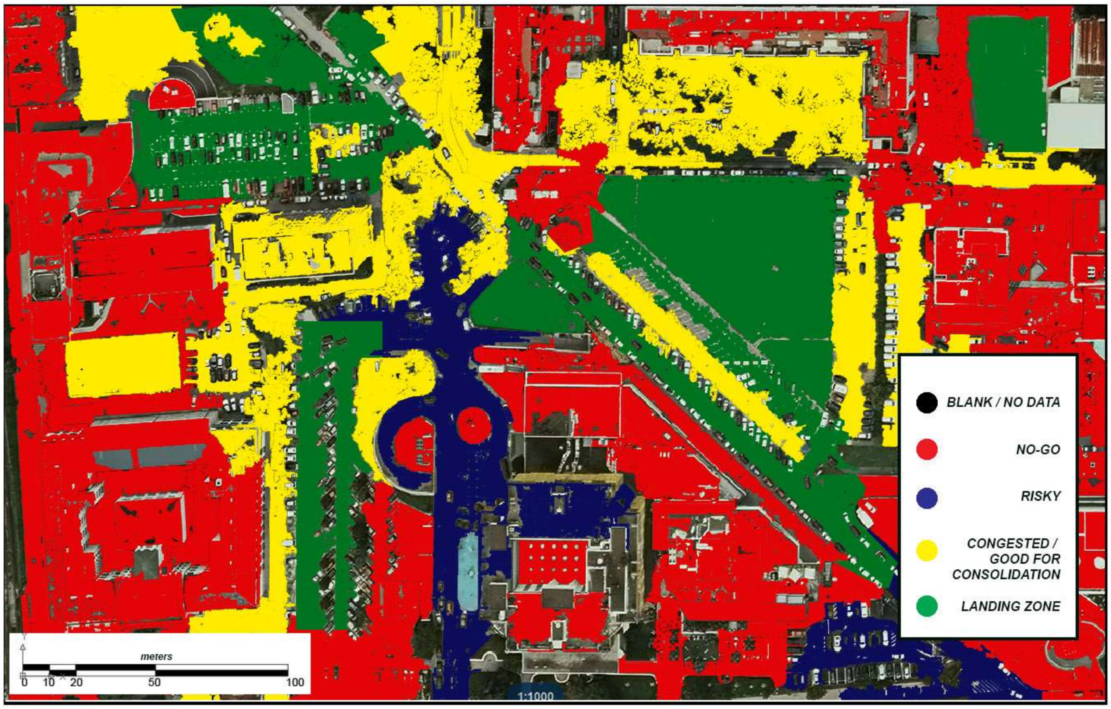

Figure 2: Example of resulting correlated and weighed risk model superposed on 2022 Orthophoto base of Sarajevo on a finer scale (1:1000 scale) in the inner-city region of Marindvor. Note that the model maintains some level of detail with the increasing scale and the number of potential obstructions, but it cannot account for ephemeral effects (i.e. cars).

2.2. QUALITATIVE EXPERT SELECTION

The qualitative element in the analysis is directly proportional to the confidence and experience of the pilot. The study involved three (3) qualified rescue pilots with over 1500 hours of total flight time, each. One of the pilots routinely flies the Sarajevo – Banja Luka areas (twice per month) and has been trained in accordance with the former Yugoslavian rotary wing operations (and subsequent follow-on army aviation commands). He is familiar with the local terrain and its peculiarities while the remaining two pilots are trained in accordance with the NATO and U.S. SAR/USAR/CSAR doctrines and are not familiar with the local terrain. The rationale for this approach is that quite a few non-native / non-local pilots are sent to Bosnia and Herzegovina to assist with the ongoing EUFOR mandate or to support various emergency contingencies (see Smailbegovic et al. 2018). The pilots were provided with the up-to-date 1:25,000 scale map, oblique aerial / satellite imagery (~1m spatial resolution), digital terrain model and the overlay with all known obstructions within the area.

Figure 3: Aircrews from Austria, Slovenia and Bosnia-Herzegovina working together to provide aerial evacuation and relief during the floods of 2014; co-author's own footage.

Figure 4: Ladden take-off from an extremely tight landing spot in NW Bosnia and Herzegovina – no quantitative model would list this site as valid LZ, yet qualitative model allows for its viability.

The main considerations performed in the qualitative selection are related to the safety of approach and departure, size of the landing zones, any potential risks to the visibility (i.e. whiteouts / brownouts) as well as the ability to clear obstacles at take-off when fully laden. The overview and ranking of the qualitative site validation, by the three pilots is shown in Table 2 below.

Table 2: Qualitative assessment score of landing zones

Factor		Pilot 1 (BH)	Pilot 2 (USA)	Pilot 3 (NATO)
Approach		Important	Minor factor (1)	Important
Departure		Decisive	Important (2)	Important
Visibility		Important	Decisive (3)	Important
Obstructions		Decisive	Important (2)	Decisive
Size		Minor factor	Minor factor (1)	Important
Coordination		Minor factor	Important (2)	Decisive
Terrain		Minor factor	Minor factor (1)	Important
"Feel"		Important	Decisive (3)	Important

Table 2 outlines the post flight-planning interview results where the pilots would rank the eight (8) determinant factors in the order of importance for the landing sites proposed, from the input data (topography, obstacles, visual, digital terrain model etc.) and the factor "punch-list." The score for each is given in the second column – Not important (0), Minor Factor (1), Important (2), Decisive (3). The limited scope shows that the BH pilot, who is relatively "fresh" from flying rescue missions in the area is the most concerned about the obstructions and departure patterns, while the U.S. or NATO aviators were more concerned about the visibility, coordination and "overall feel," particularly for the U.S. aviators.

3. RESULTS

The results of the bi-level analysis suggest that the major urban areas of Bosnia and Herzegovina have at least three ideal and five acceptable locations which could sustain large-scale emergency evacuation of affected residents (see Table 3). The ideal areas have exhibited the automated matched score of at least 8- percent and a "GO" approval from the three expert aviators. The combined approval score for the primary landing zones had to be at least 75 percent or better (combined automated and expert evaluated score) while the acceptable landing zone required at least 60 percent passing score. The choice of locations and their viability depends on the type of potential disaster, but according to the available data, it is realistic to expect that the selected locations would withstand and remain partially usable in the majority of possible emergencies. Out of approximately 38 landing zones selected by the semi-quantitative model in the five urban areas of BH, the expert aviators have invalidated 8 zones as unsafe (score <50%), 10 were graded marginal (score <60%) and 20 were graded acceptable (score >60%), out of which 5 were rated ideal (score at and above 90%).

Table 3: Landing site picks / scores

Urban area	Location 1	Location 2	Location 3	Acceptable
Sarajevo	Grbavica stadium (90%)	Skenderija (78%)	Campus (Marsal Tito) (76 %)	Kosevo stadium (66%)
Banja Luka	City stadium (92%)	Kozara barracks (88%)	Clinical center (80%)	Gov. of RS parking (63%)
Tuzla	Tusanj stadium (90%)	Former barracks (Campus) (87%)	Dramar field (75%)	Panonian lakes (if dry) (60%)

Mostar	City stadium (Zrinjski) (90%)	North University Campus (90%)	Kantarevac stadium (75%)	City pool parking (68%)
Zenica	Kamberovica field (90%)	Aux. field in Crkvice (85%)	Bilimisce barracks (80%)	City stadium Bilino. (74%)

Based on the fact that the expert aviators have invalidated eight (8) out or proposed thirty eight (38) landing sites, it is suggestive that semi-quantitative model lacks the sufficient clarity that could automatically pick all of the landing zones. The limitation is mainly data driven and embedded within model's (machine's) inability to spatially visualize all of potential hazards, that a human-operator would account for on the basis of experience and sound-judgement. The semi-quantitative model, does narrow down the suitable landing zones, which could save time when operating in an unknown area and when the evacuation clock is ticking.

4. CONCLUDING REMARKS

Given congestion of urban areas and lack of overall planning towards evacuation in an emergency, it is encouraging that suitable aerial evacuation sites exist in the major municipal areas of Bosnia and Herzegovina even though they were not planned for that exact purpose. The combined automated and expert-validated method shows potential in determining other suitable landing zones for aerial evacuation in the complex urban terrain. This is an encouraging element given the reliance of Bosnia and Herzegovina on the assistance of non-native rotary-wing crews (during emergencies) and a good benchmark goal for the future training regimen of domestic civilian and military rotary-wing rescue crews.

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