Applied Geomatics Approaches in the Maltese Islands
SpatialTrain II

Formosa, Sciberras, Galdies Applied Geomatics Approaches in the Maltese Islands

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Edited by
Saviour Formosa, Elaine Sciberras, Charles Galdies

PLANNING AUTHORITY

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That's how the light gets in

Dedicating a book is a difficult task.
A few dream, many debate,
many fall through the system,
some lead,
some implement.
All in tandem push towards achievement and it is to
These that the dedication is made.

The spatial construct hardcodes minds
but softens hearts as it delivers
art through science,
visuals through flat and pseudo3D,
and immersion.

Ring the bells that still can ring
Forget your perfect offering
There is a crack in everything
That's how the light gets in

"Anthem"
Leonard Cohen
London 2008

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Thanks goes to all those who made this book happen, the Planning Authority, the University of Malta, the ESF mechanism through the Planning and Priorities Co-ordination Division (PPCD), the different entities who partook to spatial information during the past decades striving to push GIS to its fruition. In conjunction with SIntegraM, a sister ERDF project, SpatialTrain sought to deliver the training and research component in a veritable adventure aimed at bringing together all-spatial data related entities within one single data transfer and sharing core, whilst identifying those knowledge lacunae and morphing it to ensure delivery in governance, operational functionality and academic research within a central GI core.

Thanks also goes to the authors who dedicated the past years towards the target to further their educational qualifications at Degree and Postgraduate Levels. Studying in conjunction with full time intensive employment is always a challenge but the love of the theme in conjunction with a dream to fulfill one's knowledge into the operand's functionality stays one to complete the voyage. This publication resulted from a drive to fund studies at graduate and postgraduate levels, information on which is found in the First Volume of this trio of publications entitled "Pathways to Spatial Cognition: A Multi-Domain Approach - SpatialTrain I".

The papers in this publication span diverse domains, initially launched through three scholars' works followed by chapters pertaining to four domains. The Domains include Cultural Heritage, Social Wellbeing, Infrastructure and Spatial Planning and Ancillary Domains.

On an international academic front, the collaboration between the editors, the course delivery entities and the respective tutors has, rendered a just result to each of the students who partook to the project at the L6 and L7 levels.

The authors deserve a veritable round for the endurance they showed in their drive to deliver: Annalise Agius, Debra Jane Camilleri, Jonathan Camilleri, Charlot Casha, Elysia Marie Camilleri Darmanin, Christian Debono, Karen Dimech, Claudette Farrugia, Kurt Farrugia, Andrew Formosa, Saviour Formosa, Charles Galdies, Francesca Gatt, Omar Hili, Shawn Pawney, Elaine Sciberras, Jessica Scicluna Davids, David Spiteri and Steve Zerafa.

Finally, a word of appreciation to those thematic experts who reviewed the authors' works during study and in delivering their topics for this publication.

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PROLOGUE

The SpatialTrain Scholarships Scheme Project

Elaine Sciberras

Keywords: SpatialTrain, geomatics, GIS training, spatial data, public administration

Introduction

The use of spatial data at a national level is steadily increasing due to the application of using the concept of spatial data in various thematic areas. Uses range from a simple navigation using free commercially available maps on one's mobile devices to more focused applications on querying datasets and derivation of value-added maps, statistics and information systems. At the time of writing, various entities within Malta's public administration system are already using digital maps for various applications. These range from the use of the Planning Authority's (PA) basemap and aerial imagery for spatial planning, added value maps for infrastructure and transport planning, environmental spatial data for both environmental monitoring and reporting, to comparative spatial data acquisitions using Unmanned Automated Vehicles (UAVs) and lidar scanners for detailed smaller scale analysis. At a European level, the EU's digital strategy and more specifically, spatial data, are instrumental in providing knowledge and driving policies related to issues such as the EU's Green Deal, the European Commission's Space Strategy for Europe and the European strategy for data.

The digital drive is one that should be accompanied by an equal investment in spatial information systems for the dissemination and updating of data, data harmonisation across public entities and the creation of spatial data strategies. The availability and uptake of spatial datasets enables data analysis for multi-disciplinary applications. These include spatial planning, infrastructure management, environmental assessments, preservation of our cultural heritage and understanding trends in public health or crime prevalence. Furthermore, recent technological developments in the fields of digital mapping, 3D visualisation, mobile phone apps and Artificial Intelligence provide huge potential for the intelligent use of spatial data and simulation of specific events.

The availability of spatial technologies and datasets within the public administration implies that an efficient and intelligent approach is required to take full advantage of the investment in such technologies. Training of public administration staff is key to maximise the use of spatial data within their respective entities. The specialised training in the field of geomatics within the public administration was the drive behind the Planning Authority's SpatialTrain Scholarships Scheme project.

The SpatialTrain Project

The ESF.04.071 SpatialTrain Scholarships Scheme project was part-financed by the European Union – European Social Fund (ESF) under Operational Programme II – Cohesion Policy 2014-2020, "Investing in human capital to create more opportunities and promote the well-being of society".

The SpatialTrain Scholarships Scheme provided tertiary education in the field of geospatial technology (geomatics) to the public administration within government entities. Training was offered to public administration employees in spatial data technologies and Geographic Information Systems (GIS) that were not in place in the Maltese islands in a dedicated and coherent manner. This aimed to increase the technical skills of public officials with respect to the use of spatial data and to improve utilisation of public resources in the field of geomatics.

Training and Scholarships

Four MQF levels (levels 4-7) of training in the field of Geomatics (spatial data) were offered in SpatialTrain's scholarship scheme. Level 4 (Certificate) and Level 5 (Diploma) training was provided as dedicated courses provided by a local contractor. On the other hand, Level 6 (Bachelors) and Level 7 (Masters) scholarships were offered to participants who could choose their own specialised geomatics course. In such cases, their research focused on thematic aspects relevant to their line of work within their respective public entity.

Scholarships were offered in a range of geomatics topics (Figure 1). These aimed to provide tuition on the principles of Geomatics, the use of GIS, as well as its applications in various sectors which would complement the roles of various government entities.

Figure 1: Range of study areas for which scholarships were offered through the SpatialTrain project.

Priority Study Areas

- Basics of Geomatics
- Geographic Information Systems (GIS)
- Spatial Analysis for various applications (e.g. environmental, urban planning,
- infrastructure or coastal management)
- Land surveying
- Remote Sensing
- Bathymetric analysis
- Spatial data capture and spatial data infrastructures
- Spatial data management
- Spatial simulation and modelling (Smart Cities and urban analytics; 3D modelling; geospatial predictive modelling)
- Spatial data harmonization and standardization, including compliance to INSPIRE Directive
- Remote devise pilot/controllers

Other Study Areas

- Spatial econometrics (social and economic perspectives of spatial interventions)
- Geographic Information for management staff (basic technical training)
- Spatio-political analysis
- Other related areas

Scholarship uptake by public entities

The PA's dissemination activities for this project generated a significant amount of interest and requests for information. The uptake of scholarships derived from a broad range of public entities indicating that the need for the use of geomatics training was significant. Ultimately, participation boiled down to the time commitment by the participant and support from the respective management. Indeed, some limitations to the course uptake and implementation included the occasional lack of management support to some employees to apply for a scholarship or drop-outs of some students due to the work commitments.

Scholarship uptake was multi-disciplinary. In fact, scholarship applications at all four MQF levels were received from diverse public sector entities:

1. Ambjent Malta
2. Department of Public Health Medicine
3. Environment Resources Authority (ERA)
4. Heritage Malta (HM)
5. Malta Air Traffic Services Ltd (MATS)
6. Malta College of Arts, Science and Technology (MCAST)
7. Malta Communications Authority (MCA)
8. Malta Council for Science and Technology (MCST)
9. Malta Police (MPF)
10. National Statistics Office (NSO)
11. Planning Authority (PA)
12. Restoration Directorate
13. Superintendence of Cultural Heritage (SCH)
14. Transport Malta (TM)
15. Water Services Corporation (WSC)

These public sectors were already somewhat exposed to the importance of spatial data to address analytical, reporting or policy issues within their entity. This exposure varied from a general overview to one where spatial data are already part of their standard working practices. Consequently, the entry knowledge of trainees varied from ones who had no prior use of spatial data/GIS to others who planned to expand their knowledge of spatial data to tackle in-depth applications of geomatics.

The SpatialTrain Book Authors

This forthcoming chapters in this book pertain to the research carried out by the SpatialTrain scholarship participants at MQF L6 and L7 levels. These chapters provide a synopsis of their dissertation research and aim to deliver a flavour of geomatics' applications in various thematic regimes. All SpatialTrain participants who contributed to these chapters completed their academic degree on a part-time basis whilst carrying out their duties within their respective public entity. Their determination and efforts, together with an understanding of the value of geomatics for their work duties, are highly commended.

The Way Forward

The SpatialTrain Scholarships Scheme project was a first major step on a local level to provide accreditation of the public sector within the field of geomatics. It is expected that this will not be the last training initiative. Future dedicated training initiatives in the geomatics sector will continue to be required at the various qualification levels. Furthermore, projects which require cross-entity contributions will require sharing of dedicated knowledge in various aspects of geomatics. It is this type of contribution which should provide the impetus for a national spatial initiative. Such initiatives would help to conduct geomatics research, training, and spatial initiatives, provide guidance on geospatial standards and policies, and build an active network in the field of geomatics. It is the integration of the knowledge gained, data sharing and standards which will contribute towards a national coherent effort in the field of spatial initiatives.

INTRODUCTION

Pushing the Envelope on Spatial Information? The Where Factor

Saviour Formosa

Information dynamics revolve around the W6H factors: What, Who, Why, When, Where, How and Why Not? Research focuses on one, two or all such factors. GIS and the study of spatial science revolves around the Where Factor. Locational science combines the entire data cycle: design, capture, cleaning, analysis, outputs and dissemination. Each step revolving around the issue of location: a unique space that inhabits a singular x,y coordinate upon which attribute or thematic data is sewed. This combination of a point in space and the relative thematic elements creates information: information refers to the meaning given to a datum: each on its own does not necessarily garner insight but once wed, the result depicts an information module which combined further with context renders knowledge and in turn wisdom and potentially action.

The Where factor was iconic till some years back offering recollections of large wooden extracts called paper map which we travelled with whilst an acquaintance was busy driving around the throughfares. Paper that offered wonders and a chance to trace one's journeys we travelled. Not any more…

As spatial-tethered hardware and software became available, initially through mobile road maps and now integrated in one single device that also markets itself as a phone: one cursory look at the 'phone' or better yet a 'handy in German' posits a GPS, a dog tracker, real-time traffic information and directions to travel, a plane and ship locator, a walking assistant, a measurement device, a LiDAR scanner, a photogrammetric tool, an entire global map, a UAV pilot and flight planner, a UAV forecaster, an item locator, a VR, AR and MR device… so many tools so little time to use but a fraction. Thus, the point in space has become gradually unobtrusive and content took centre stage. Location is pivotal to all this brave new world, even more importantly as users gradually use their ability to understand space, read maps and drill into the layers behind the content they view. Even going from one place to another, we have an assistant that states direction, distance as we drive a vehicle in real space. With Level 5 Full Self Drive, robotic vehicles will only require a destination and unobtrusiveness would have created another knowledge loss and further dependency on technology.

Such explains the original strive to develop SpatialTrain, which aimed to equip tomorrows policy-makers and decision-takers working in multi-disciplinary domains to seek qualifications through degrees and post-graduate degrees. Empowering people in Spatial Information serves as a springboard for the retention of spatial knowledge and the dissemination of that wisdom for strategic, operational and tactical societal enhancement.

Elaine Sciberras in the Prologue describes the role that The SpatialTrain Scholarships Scheme Project had in bringing together experts in the different domains and who converged around a single point of reference: the spatial construct. The papers in this publication are testament to such. Sciberras explains that "The SpatialTrain Scholarships Scheme provided tertiary education in the field of geospatial technology (geomatics) to the public administration within government entities. Training was offered to public administration employees in spatial data technologies and Geographic Information Systems (GIS) that were not in place in the Maltese islands in a dedicated and coherent manner. This aimed to increase the technical skills of public officials with respect to the use of spatial data and to improve the utilisation of public resources in the field of geomatics."

This publication brings together the results emanating from these studies at MQF Level 6 and 7 (Degree and Post-Graduate Degree levels). It is with pleasure that the editorial team presents these degrees offered a widening of the GI knowledge base that will maintain the current and enhance the use and implementation of spatial information and the eventual action which it instigates.

The publication contains three dedicated editorial papers and sixteen chapters authored by the SpatialTrain contributors: new knowledge categorized in four domains: Cultural Heritage, Social Wellbeing, Infrastructure and Spatial Planning and Ancillary Domains. As detailed in Volume I of this 3 volume publication "These chapters can be recategorized by method, delivery, analytics and other facets, however the integrative aspects is pivotal to all as each chapter posits a drive towards spatial functionality that is the Maltese State".

Thinking Spatial

The first section focuses on three scholars's drive to push GIS to new heights through their focus on spatial and temporal studies and their impacts of aviation, land cover and crime.

Chapter 1 by Charles Galdies states that pavement roughness evaluation of airport runway/taxiway has to be done according to well-defined procedures in order to ascertain proper water flow from runway surface and to ensure that surface roughness is within safety margins. Airport tachymetric surveys are routinely carried out using traditional topographic techniques, but these are very labour intensive and not very productive. An alternative and comprehensive survey method that considers the surface of entire runway areas at a high accuracy, sampling density and speed is the use of LiDAR. In this paper an analysis is presented based on a dataset consisting of 1m by 1m area segments of an international airport taxiway from which spatial parameters of interest were derived and associated with spatio-temporal (climatological) weather precipitation occurrences in support of future safety management of runway surface conditions.

Chapter 2 by Elaine Sciberras focuses on the Copernicus Land Monitoring Service (CLMS) that offers a range of time-series spatial data related to land cover (LC), land use (LU) and bio-geophysical parameters. CLMS products at pan-European and local level offer a range of thematic land cover maps at various spatial resolutions. Such outputs are available on a full, open and free-of-charge basis and therefore enable product uptake for various land cover applications. Furthermore, the new CLC+ product suite will use advanced technological developments and the legacy of the European CORINE Land Cover (CLC) flagship products to enable users to create tailor-made LC/LU products using CLC+ products. The need for harmonisation across EU Member States implies that products vary from a low spatial resolution up to 10m resolution. This poses a challenging situation for Malta due to its geographical dimension as well as the diverse range LC/LU classes occurring over a relatively small area. The spatial resolution component can affect the extent of user uptake by Maltese public authorities of CLMS products available at a European level. This paper provides an overview of the data available for Malta, including the work carried out by the Planning Authority as the national relay contact for land cover. This includes the production and verification of CLC and High-Resolution Layers (HRLs). An insight into the upcoming CLMS pan-European products is provided as well as the challenges in the Maltese scenario for user uptake of CLMS products within the public administration.

Saviour Formosa in Chapter 3 revisits crime through its employment of GIS and LiDAR technologies as a stepping stone to crime scene reconstruction. The paper discusses the difficulties encountered in introducing a new methodology in a traditional and conservative domain averse to technology is never a Euclidian straight-line process. The path is winding, requiring years to prepare, convince and present the findings. Spatial Forensics is a scientific process aimed at the study of the data cycle pertaining to a crime scene. The design, capture, cleaning, analysis and presentation of the results in a Court of Law requires solid theoretical, factual and methodological protocols steeped in the science of data. Formosa focuses on the theoretical approach behind spatial forensics and how evidence in crimes is instantly vapourware due to its short lifespan unless captured in a digital world that allows for future strategic, operational and tactical investigations. The methodological processes described posit some thoughts on the steps entailed in data capture, retention and depiction of scene reconstruction through a technological approach to research.

The Cultural Heritage Domain

The second section of the publication depicts chapters on taskscapes in Neolithic Malta, Sites risk management, osteological analysis, cart ruts archaeological negative data, and an interesting take on WWII defenses.

Annalise Agius in Chapter 4 sought to explore the relationships between megalithic monuments, funerary and domestic sites, and the affordances of the surrounding landscape. Gibson introduced the idea of affordances, which are defined as intangible properties offered by the environment that cannot be easily understood, depicted, or portrayed. These affordances impact how humans interact with their surrounding environment. The study compared the data from the different site clusters within Malta and Gozo. It examined patterns in the relationships between the location, the site catchments through Site Catchments Analysis (SCA) with different walking times, using Tobler's off -path hiking function. Viewshed analysis over these two classes of sites was also explored. The research explores the known characteristics of the territory visible from these sites within their landscape and taskscape setting, by exploring the relationship of the sites with the surrounding geology, soil families and soil complexes. Agius further analysis the relationship between visibility and site catchment was examined closely and as noted through site catchment analysis, all types of sites are very closely connected with each other and within the landscape in terms of walking distances. Although such a relationship is also observed visually through the cumulative viewshed analysis sites for megalithic sites, their surrounding sites, landscapes and taskscapes (a socially constructed space of human activity with a spatial boundary), such a pattern is not mutually reciprocated for funerary sites and its surroundings. Thus, the intervisibility between megalithic monuments and funerary sites is not mutually reciprocated between all sites.

Claudette Debono Farrugia in Chapter 5 studies culture, the way of life especially general customs and beliefs of a group of people, and heritage, features belonging to the culture of a particular society, are considered as one of the four pillars of sustainable development and investment and heritage can generate return in both social benefits and economic growth. However, the protection and maintenance of cultural heritage is seen to be reactive rather than proactive. This results in a general unwillingness to dedicate better resources to minimise all kinds of risks related to the protection of cultural heritage. This study explored the possibility for cultural heritage managers to analyse risks affecting cultural heritage sites using geographic information systems to be better manage their financial and human resources. An extensive review of the literature was carried out in order to extract risks affecting cultural heritage sites in Malta. Datasets from which the risks can be extracted were sourced online, as open source/open access. The analysis of this study employed fuzzy logic as it enabled the synthesis of more realistic results. When considering deterioration mechanisms as a spatially vague phenomenon, then the application of fuzzy logic was deemed appropriate. The results of the study indicated which sites are most at risk and were further confirmed both through a sensitivity analysis of the model developed as well as on an onsite visual analysis.

Chapter 6's author, Debra Jane Camilleri describes the 1969 discovery of a large assemblage of commingled skeletal human remains found in hidden rooftop passageways at the 15th century old parish of St. Catherine's, now known as the Chapel of San Grigor in Żejtun, Malta, has intrigued locals for decades. Believed to be remains of victims of an Ottoman attack in the 17th century, studies conducted ten years after the discovery left questions unanswered about the time period from which they originated, population affinity, and how they came to be in these passageways. A demographic analysis (sex, age, ancestry) was performed in this study, incorporating recent radiocarbon dating results and extensive archival research. The results showed that the remains included at least ninety-two males and females who were primarily over the age of 50 years at the time of death. While most were European, a small percentage were of sub-Saharan ancestry. To obtain evidence that the site was not a primary burial and rule out interpersonal violence as the cause of death, a GIS-based approach was used to analyse and visualise, and determine patterns from large amounts of archaeological data. Base maps were created using scanned images of femurs as the 'geographical landscape' on which various features (antemortem fractures, postmortem taphonomic processes, and tool marks) were 'mapped' to generate a spatial representation of the density of these features. The results from the GIS-based approach along with statistical analysis showed the advantages of using several techniques to understand commingled remains in archaeological and historical settings and encourage the future use of GIS in managing, analysing and visualizing data obtained from the study of human remains.

Elysia Marie Camilleri Darmanin in Chapter 7 focuses on the archaeological significance of rock cut pits identified in the limits of Ħal Safi and Gudja between 2014 and 2019. Camilleri Darmanin states that in recent years, the Maltese Islands have seen an increase in development applications. This leads to important archaeological discoveries through applications that include development-led archaeology. In recently development-led applications, two sites containing a substantial number of circular rock-cut pits, commonly known as silos, were discovered. Furthermore, after gaining access to recent data collected by the state regulator, the Superintendence of Cultural Heritage (SCH), sites with similar characteristics and contexts are located only a few metres away from the two locations that will be included in this study. These sites have created a similar archaeological setting in which there are several silo pits. The data and knowledge gained from SCH interventions and data provided of various sites with similar discoveries, along with information available from local plans of different regions for the Maltese Islands which are intended for planning purposes, and the existing literature, present similar archaeological contexts for the two sites which will be the focus for this study. These similarities have prompted interest to further analyse the significance of these findings in the landscape of Ħal Safi and Gudja. Try to understand, through GIS, the context and any other contributing factors that lead to any socio-economic or environmental interactions that require the rock excavation of these pits.

Chapter 8 gives readers a though provoking question. The author Jessica Scicluna Davids, looks at Inference from Absence. The nullity of something could offer evidence that it existed. The concepts of hidden archaeological landscapes, site formation processes, together with inference from absence of archaeological discoveries were assessed to understand archaeological negative–data sites which did not yield archaeological discoveries in an area where remains are abundant. An area with a considerable number of archaeological discoveries and development-led monitoring (archaeological monitoring carried out during private and public development works as per Cultural Heritage Act) was selected since such a location presented the most significant data for analysis. For this reason, the Area of Archaeological Importance (AAI) of Rabat, Malta was selected as the area of study. Given that Rabat's uninterrupted human occupation dates back to the Bronze Age, its cultural landscape is mostly hidden. Specific areas within the AAI were selected for the in depth-analysis. Data derived from the Planning Authority and the Superintendence of Cultural Heritage was plotted on a GIS so as to build a geodatabase. Various GIS tools were used to extract relevant data such as listing of archaeological sites by year of discovery and typology and sites which did not yield any archaeological discoveries within an archaeological constraint zone. This, correlated with the topography using GIS, provided information on the location and nature of an archaeological discovery. 436 discoveries were made through different forms of archaeological monitoring between 1624 and 2020, exponentially rising since the introduction of regulated archaeological monitoring in 1997. 884 negative sites were identified, namely unmonitored works prior, but not limited to, the promulgation of the Cultural Heritage Act of 200 The results ultimately showed that there are a number of reasons for negative data within a rich archaeological landscape.

The final paper's author in this section, Kurt Farrugia, analysed whether the Axis Powers, Germany and Italy made a justified decision in the abandoning of Operation Herkules, the plan to invade the Maltese Islands during the Second World War. This study determined this by means of a spatial analysis of the military defences located on the islands at the time, which mainly consisted of anti-aircraft batteries, pill boxes and other types of fortifications. The method adopted consisted of the GIS plotting of these defences, in order to gauge their concentration. This study provided a spatial output of potential killing zones for any invading troops. Although the plotting is not exhaustive due to the little information related to mobile defences, as well as missing information about defences that were removed immediately after the war to make way for modern development, the end result of this study indicates that any attempt at an invasion would have resulted in heavy losses for the Axis powers due to the concentration of defences around the island.

The Social Wellbeing Domain

The third section, comprised of four papers focuses on the use of GIS to study social issues with a single paper on the investigation of browser-based map accessibility for visually impaired users and three papers on crime-related issues.

Chapter 10's author, Charlot Casha, visits crime and crime distribution by type, space and time, is an ongoing process explored by several scholars, criminologists, and scientists. Progression in Geographical Information Systems (GIS) enhanced the significance of crime mapping and spatial crime data analysis. Thematic crime maps are valuable for the study of the location and ecological aspects of crime. Simple or complex spatial crime analysis submits a pictorial representation of the results in the real geographic environment of the study area. Law enforcement organizations have certain legal privileges for the collection, sharing and retention of data; hence, crime mapping analyses and tangible spatial analytical processes may be created to develop and enhance the efficiency of the databases analytical processes. This study explored a range of techniques and technologies being implemented to cover crime mapping and spatial crime analysis methodologies so as to propose a potential fit for a purpose GI solution to the Malta Police Force (MPF). Acquired theft data together with demographic data for population in Malta were used to explore a series of non-spatial and spatial crime analysis. These processes, together with the outcome of the research in this study, promote a combined hybrid GI solution for crime spatial analysis. The GIS solution enables MPF to develop the strategic contextual model for intelligence-led and pro-active policing, crime prevention, crime scene investigations and criminal investigations.

Karen Dimech in Chapter 11 states that interactive online maps are often used in everyday life as a guide to familiarise oneself with a specific location and any features of interest ahead of time and plan accordingly. This study sought to understand this activity from the perspective of visually impaired users, with the aim to inform a design of an online interactive map which is accessible for planning ahead and map familiarisation. For this reason, we conducted a three-phase mixed-method research, where in the first phase, a study with ten visually impaired persons was held, through which a user-group specific information architecture emerged. Card-sorting was used to develop a mental model, while semi-structured interviews contributed richer insights which further enhanced this model. In the final phase, a prototype-SonoMap, was developed, where the insights gathered from the previous phases were applied and through guided interviews, feedback and results were gathered. Experiences, insights and results from this study were obtained. Through this application and techniques implemented, visually impaired users were able to successfully familiarise themselves with a specific location.

Omar Hili in Chapter 12 aimed to design and implement a Spatial Data Infrastructure (SDI) to house geospatial data with an online portal to allow the general public and local government authorities to report a crime from a geographical point of view. The methodology adopted was a primary investigation with focus on the needs of the user as to understand similar systems so as to design the front and backend infrastructure for successful completion of the project. From the base research and interviews conducted, the user requirements were extracted and noted including the functional requirements of the system. The main functions of the system were to plot crime as spatial points, the ability to perform street searches, filter by crime category, spatial query for local councils and generation of heatmaps. The project exposed the potential to be used both by the public to report crimes and by the police to visualise and analyse the public data. The study also described the use of freeware to visualise the same data which was inputted through the portal in real-time and using an advanced query. The proposed portal has significant potential to expand on various platforms and operating systems as the services are mostly consumed via a published URL service, and therefore offer the ability for use on different platforms as devices. This is a unique system for Malta which incorporates ICT technologies, geospatial concepts and analysis to provide a public server to local enforcement authorities and the general public.

Chapter 13 states that crime data in Malta is often presented as raw figures or are presented as crimes for a particular number of the population, treating every crime as equal The author, Shawn Pawney notes that not all crimes are equal, and not all have the same toll on society at large. The aim of the study was to geographically illustrate a different way of measuring crime and to illustrate the differences and convergences between using prevalence data and a weighted score. The study also aimed to illustrate the significance of using a weighted crime index as opposed to only relying on prevalence (crimes per 1000 inhabitants) crime data. The approach was to create a prevalence and weighted crime index for each locality based on existing crime data and, after mapping all the data, to illustrate the geographic distributions. Further analysis was conducted by comparing changes in geographic patterns of crime prevalence and crime severity on the local scale in the time period between 2016 and 2021.

The Infrastructure and Spatial Planning Domain

The fourth section, comprised of three papers focuses on the use of GIS to study urban sprawl in Victoria Gozo, water consumption and spatial algorithms.

Chapter 14's Andrew Formosa argues that amongst the wide-ranging applications of Geographical Information Systems (GIS), investigation of urban sprawl is an established practice. Analysis of urban sprawl in Victoria, Gozo over three centuries (1804 till 2018) and the chronological logging of built and non-built-up areas are presented in this paper. A mixed methodology approach was applied and included the digitisation of both historic maps and aerial photography and the application of aerial remote sensing. Data analysis on urban and green space in Victoria was based on a 100m2 sampling grid in order to compute data on urbanisation. The grids were utilised to quantify both built and non-built-up areas for all reference years. The methodologies adopted for this study confirmed that urban sprawl maintained a slow rate up till the 1940s, gaining momentum from the 1960s onwards. This research attested how certain parts of Victoria have practically been metamorphosed from completely green areas into built-up areas. Amongst the main results of the project is the fact that the percentage of built-up areas in Victoria increased from 2.4% in 1804 to 32.7% in 2018. Concurrently, the non-built-up areas decreased from 97.6% to 67.3% for the same period under study. The analysis by the 100m2 grid showed how the category having at least 80% of non-built-up area in each grid decreased from 211 grids (61% of total grids) to 95 grids (28% of total grids). The study emphasised the importance of GIS in calculating urban sprawl and promoting the correct use of planning and safeguarding of green areas.

Christian Debono in his Chapter 15 focuses on the ever-increasing challenge of global warming and rapid population and economic growth in the Maltese Islands was used as a baseline for change analysis. Water demand and consumption are increasing and becoming more challenging given the water scarcity the Islands register. Several water consumption determinants were identified to better understand what affects the demand. These included mainly population related variables which were used as independent variables for spatial regression models. The spatial regression models were used to determine the relation between the determinants and the average water consumption while identifying spatial effects across the Islands. First, an Ordinary Least Square (OLS) model was applied followed by a Geographically weighted regression (GWR). The monthly water consumption data from the last ten years was obtained from the Water Services Corporation (WSC) of Malta, which included the average consumption of households aggregated to the Local Administrative Unit (LAU) to preserve data anomalies. The data was aggregated into quarterly periods to reduce the number of datasets and to reflect seasonality in the data, while three different years were analysed. Each year was selected based on a particular event associated with it i.e., the introduction of smart water technology in 2010; the reduction in water tariff prices in 2014 with the year 2015 being the first full year with a lower water price tariffs and the global pandemic of Covid-19 in 2020. The performance of the GWR was far better than the OLS, although results showed that the determinants analysed contributed to the models and there is still room for improvement, by including different independent variables. The residual maps obtained from the models highlighted the areas where demand is particularly high and require the most attention to meet the population needs.

The final paper in this section, Chapter 16 by Steve Zerafa covers a study that was performed by utilizing the Sentinel 2 satellite images of the Maltese islands acquired from

2017 to 2020. The aim of the study was to evaluate the dynamics of the NDVI covering the Maltese island by using Sentinel 2 datasets. And from patterns relate different surface and land cover categories to NDVI classification, produce a bi-temporal land surface change analysis, and separate two locally popular summer and winter crops, grapes and potatoes, from others using yearly NDVI patterns. The results showed that the NDVI mean value for the Maltese Islands fluctuates by a value of 0.25 every six months, and that between Spring 2017 and Spring 2019, the vegetation greenness on the Maltese islands decreased by $2.45km^2$. The study also showed that there is a high concentration of grape fields, in the North-west of Malta, at Mgarr, Zebbieh, Mtarfa, Ta' Qali, Chadwick lakes, and a few scattered fields in Gozo, with the largest ones located between Xaghra and Ramla Hamra and in Xewkija area. On the other hand, potatoes were primarily cultivated in the southern regions specifically Qrendi Mqabba, Zurrieq Zabbar, and Siggiewi, and some other in scattered parts in Gozo, where most of the cultivation is done in the western part.

The Ancillary Domain

The fifth section, covers three papers that whilst related to the operational aspects around which spatial data interacts, live in their own ancillary domain. The papers look at mitigation of attacks on sensor IoT networks, classification techniques and stakeholder involvement in planning.

A sensor IoT network attack study in Chapter 17 is presented by David Spiteri in his depiction that spatial data is gathered by geolocated sensors, then fed into a repository core system, combined with other datasets gathered by other various geolocated sensors capturing diverse domain parameters and further developed in a way that enhances intelligence or solve specific problems. These geolocated sensors are highly vulnerable smart devices that can easily be exploited by threat actors and execute a Denial of Service (DoS) or a Distributed Denial of Service (DDoS) attack aimed towards the core system. This will seriously affect the spatial data's availability and integrity factors. The aim of this thesis was to propose a mitigation solution to defend against such attacks to increase the availability and integrity factors of spatial data. This was achieved through a solution based upon the Moving Target Defence (MTD) strategy in order to defend the targeted core system. A simulated prototype of the solution proved 100% success rates in mitigating sequential and en masse DoS / DDoS attacks, and a substantial reduction on the negative impact of spatial data availability and integrity factors.

Chapter 18's author, Francesca Gatt focuses on a nation's urban planning system should cater for the needs of its communities in terms of social, economic and environmental aspects through effective analysis of spatial data. National consultative authorities, government entities, urban professionals and academics including planners, architects and project managers, non-governmental organisations and the general public should embrace the opportunity to contribute, collaborate and share knowledge between themselves regarding urban planning proposals through such data. Studies on Malta's planning system in the last decade have concluded that any lack of public participation and stakeholder involvement may have contributed to an outdated and weak planning system, to the detriment of the country. Key results and recommendations include the presence of independent academics and professionals in land use discussions throughout the project lifecycle to objectively criticise proposals, assessments and recommendations of regulators and entities within ministries. The use of sharing of geomatics data through one integrated GIS system considering constraints, issues, and valuable data on sites is also a valuable tool for the encouragement of stakeholder involvement in urban planning in Malta.

Author Jonathan Camilleri, in Chapter 19 describes one of the primary tools used for healthcare in assisted living is Human Activity Recognition (HAR), which uses spatial and context data gathered from any number of sensors on the subject and/or the environment to predict the current subject activity. With limited public HAR datasets, there are no standards for the process of designing a new dataset. In this research, a multi-phase study was designed to review and apply classification techniques which target public HAR datasets to the Pervasive Electronic Monitoring (PEM) dataset; and analysing the end result. Four studies were visited to analyse the classification techniques that were used to determine the activity being performed from the raw sensor data. Nonetheless, each dataset contained specific formats, activities and spatial information and therefore some techniques may not have the same performance when applied to a different dataset. From this study, it was established that from the ten different techniques that were tested, only one failed to produce similar results than stated in the original study as it was proven to be highly specific to its respective study with limited information for replicability.

In the Epilogue, Charles Galdies posits some thoughts on the imperatives that are terms spatial information and its import for societal change.

In conclusion, this publication delivered twenty-one research-based endeavors in spatial information and how it can be designed, captured, analysed and outputted for academic and policy as well as operational consumption.

Thinking Spatial

CHAPTER 1

Use of high resolution spatial and climate data to evaluate airport runway surface evenness flooding potential

Charles Galdies

Keywords

Tarmac surface roughness evaluation, airport runway, airport taxiway, LiDAR, spatial parameters, climatology, runway surface conditions, international airport, climatological, precipitation, weather

Introduction

Airports offer a lifeline in terms of transportation of people and essential goods. They are vital for insular environments such as densely inhabited islands such as the Maltese archipelago. Continuous research is therefore necessary to continue improving operations by introducing to the airport industry new technologies and innovations stemming from other fields. This study offers a show case example on which Malta's airport industry can make use of innovative solutions to meet the demands posed by international regulations in the aviation sector.

Aircraft safety is a highly important aspect in the field of aviation transport management. There can be numerous hazards posed to the aircraft while in operation on the runway, especially during landing and takeoff. Plane safety during these two critical phases is especially related to both external (i.e. those related to the weather, especially to rainfall intensity) and internal (i.e. those related to the pavement macro texture and the friction properties runway conditions) conditions (Cao et al., 2014). However, these two can be intricately linked together as discussed further below. Impacts can be significant and varied, ranging from additional costs related to airport labour, equipment and materials, passenger delay, carrier delay and aircraft damage costs.

Weather conditions play a significant role aircraft safety. According to Benedetto (2002), accidents related to adverse weather amount to 29% of the total, especially during landing and takeoff. The intensity of significant weather impacts varies depending on the airport and its local climatology. Extreme heat, torrential rains of short durations, lightning etc are characteristic events in warm and relatively dry climates such as that of the Maltese islands. The evolution of transient rainstorms can create hydrological problem especially if long-enough climatological trends are not considered at the project phase of the design, construction and maintenance of the runway itself.

Heavy rainfall could impart severe and adverse consequences to aircraft. When an aircraft flies under rainy conditions, particularly during landing and takeoff phases, its flight safety can become under high risk. The scope of this chapter goes beyond such risks to aircraft; however, a short list of adverse risks include reduced visibility, reduced accuracy of aircraft measuring instruments, enhanced downward forcing and backward momentum to the upper wing surfaces and front part of the fuselage, condensation of water vapour above the air foil that could lead to destabilization of the boundary layer, increased roughness of the wing surfaces, and increased aircraft mass.

What is more relevant here is the increased danger caused by the resultant standing water on the runway especially during both aircraft landing and takeoff. Large accumulations of water due to runway unevenness can lead to 'hydroplaning', which tends to cancel out the braking action, resulting in longer stops or even sliding off the main runway. Empirical evidence shows that even small amounts of water on the runway may have a significant effect on aircraft performance (ICAO-RASG-APRAST, 2013). This emphasizes the need to have good drainage on runway surfaces since the drainage capabilities of any runway exposed to heavy rain can be exceeded, especially if surface maintenance has been overlooked. Runway unevenness may lead to the formation of water pools as shallow as 3mm in depth that can start to trigger hydroplaning. It is therefore necessary and important to prevent these from forming as much as possible. This is normally provided by adequate longitudinal and transverse sloping of the runway, as well as by a reduction of its surface roughness.

Hydroplaning is the cause of many aviation accidents (Aviation Accidents, 2018). A well quoted accident is that of 8/10/2004 in Bangladesh when an aircraft headed off a flooded runway due to the failure for braking while takeoff. The physical aspects of the water film affecting the braking performance include its thickness (which in this case is of primary concern), viscosity, temperature and density (Agrawal, 1986). An increased water thickness on a runway surface will in turn decrease available the friction coefficient which is a function of speed.

In addition, uneven runway surfaces directly influences aircraft components during takeoff and landing maneuvers, forcing higher material stress and fatigue which could lead to breakdown of mechanical parts (such as cabin vibration, extreme g-force, loss of adherence, etc).

The evaluation of runway roughness requires series of different measurements which are often subject to strict rules and international standards. Moreover, the kind of instrumentation and their required precision and accuracy are mandatory, not mentioning the modality of the data output and reporting. Surveys of the surface characteristics of airport runways are generally made to verify the flow of water from the surface and to guarantee a perfect surface regularity that guarantees safe aircraft maneuvering. Determining the runway surface roughness has become important in order to verify the adequate international standard requirements. According to ICAO, which is the International Civil Aviation Organisation that regulates civil aviation with the aim of standardizing procedures for air traffic management of airport runway and taxiway, supervision and maintenance of airport runway are based on the adoption of a Pavement Assessment Programme (PAP). International procedures in Malta are ratified by Transport Malta through its Civil Aviation Directorate. PAP supports methods surveying methods that examine the runway condition and without causing any damage or modification to the pavement surface (ICAO, 2001).

Traditional tachymetric surveys aim to verify at a high precision the main slope axes of the runway, taxiway and apron area, allowing the evaluation of their roughness parameters. Traditional topographic surveys make it possible to measure coordinates of the whole pavement through control points. However, the use of the total station has strong limitations due to the required point density in such cases, equal to the spatial continuity of the acquired information (usually measurements are taken at best with a grid of 10 m by 10 m). This drastically limits the possibility of holistically evaluating any localized deterioration over the entire runway.

The scope of this study is to show how the use of airborne LiDAR can in principle be used as an alternative runway control instead of traditional tachymetric surveys. Considering the performances of the most recent LiDAR instrumentation in terms of range, accuracy, point density and rapid acquisition, such instrumentation is bound to offer an interesting opportunity to measure the degree of runway unevenness and identify the current runway surface conditions to highlight problematic areas that could potentially give rise to wet surfaces or the occurrence of water patches or standing water. This exercise is relevant to ICAO Regulation requirements – 309.305(a)(6) stating that pavements shall be sufficiently drained and free of depressions to prevent ponding that can either obscure marking or impair safe aircraft operations. One important objective of our experimentation is to define, from an operative and computational process, a good index that can be used to quantify and spatially map runway surface unevenness from LiDAR.

This study is also tied to an assessment of the likely risk posed by extreme rainfall events on the basis of climatological study over Luqa airport, relative to other geographical locations in the central Mediterranean; including the determination of the return periods of extreme weather variables (such as rainfall rates and hailstorms) over Luqa airport which could pose potential flooding problems over the short and medium-term periods of time. In doing so, this study tries to provide some fundamental information in support of any future actions required to understand, monitor and predict runway flooding during severe weather conditions.

Methodology

This section describes ways how climatological rainfall characteristics and related hazards over the Maltese islands, particularly over Luqa airport, were gathered and analysed with a view of looking at the existence of risks to runway flooding, and therefore enable airport management and air traffic controllers to take the necessary protection measures.

It is important to point out that this study was carried out in 2018, after which intensive maintenance works were carried out at parts of the runway to increase its safety. These included runway re-surfacing as well as the installation of rainfall flood sensors at critical points along the runway.

In this study, the term 'weather extreme' applies to whenever the values of particular meteorological variables go beyond pre-defined (i.e. climatological) thresholds. A 'return period', or recurrence interval is hereby defined as an estimate of the likelihood of an extreme event to occur.

Local trends in rainfall: Climatological precipitation data over Malta Luqa Airport were collected from the European Climate Archives.

Two precipitation indices were chosen for this analysis: (1) CWD (Maximum number of consecutive wet days; the highest number of consecutive wet days where precipitation is more or equal to 1 mm a day), and (2) R20 (Heavy precipitation days with more than 20 mm, where days with precipitation of more or equal to 20 mm a day are counted). The entire dataset covered the period 1973-2013.

Analysis of extreme precipitation events: Additional meteorological data was gathered from land observations reported by the WMO climate station situated at the Luqa Airport (Malta), included rainfall levels and rates, occurrences of hail, etc. In this study, rainfall rate is the linear accumulation depth at ground level per unit time (usually in mm/h) used to characterize rainfall at ground level.

Time-series trends: Surface meteorological observations published every 30 minutes by Malta's Climate station at Luqa Airport were analysed. Only the long-term trends of the occurrence of hail events (1973-2009) and the maximum hourly rainfall (1959-2015) rates were analysed in view of time constraints available for this study.

This part of the statistical analyses incorporated data homogeneity testing, cumulative density functions, non-parametric correlation analysis and return periods, were carried out on the basis of the reference meteorological and hydrological data.

Topographical and surface texture information: Runway topographic data was derived from European Regional Development Funds (ERDF) project carried out in 2011 aimed at improving the national monitoring programmes on water, air, soil, noise and radiation. This data set consists of a 1m grid resolution covering the entire Maltese islands with a stated height accuracy of less than 10cm and with a generated LAS point cloud of 4 points per meter (ERDF 156 data, 2013). A set of high resolution 1m x 1m pixel raster maps were available by this project and used as the basis for analysis by this study. Dedicated hydrological raster processing was carried out on this dataset to generate a unique set of high-resolution GIS-raster maps describing hydrological characteristics such as the 'topographic wetness index' (TWI), which identifies pixel cells situated in depressed areas having a small vertical distance to a water channel.

The use of this index rests on the fact that topography is a first-order control on spatial variation of hydrological conditions. Since topography affects the distribution of moisture accumulation, this index has been developed to take into account the upslope contributing area and geometric functions. TWI was developed by Beven and Kirkby (1979) as part of the runoff TOP-MODEL and can be defined as shown below:

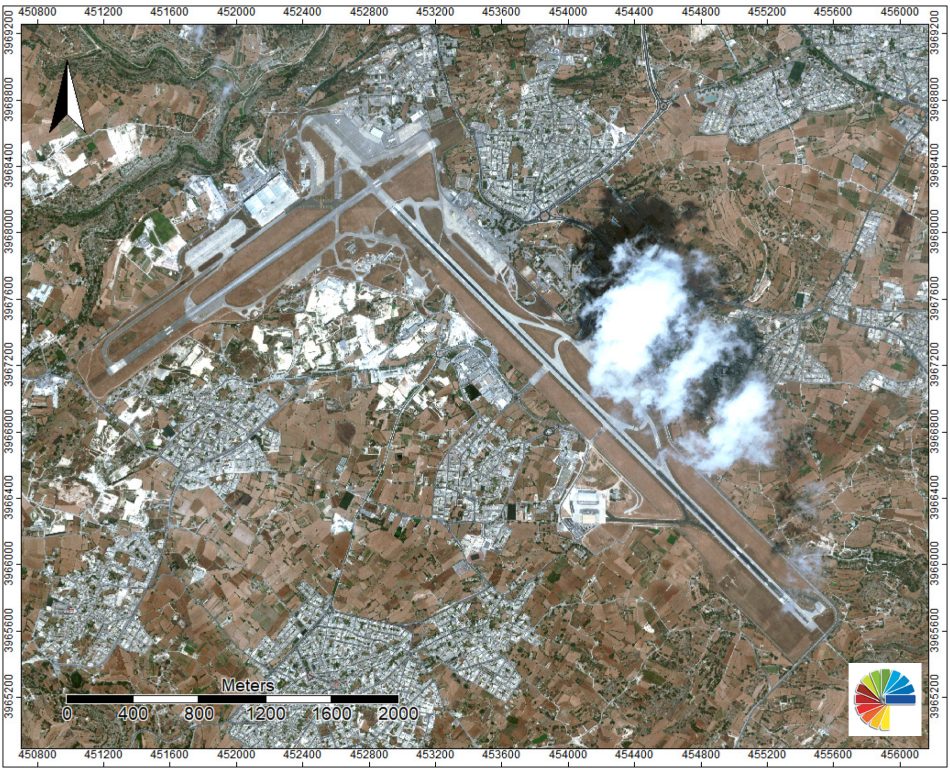
$$TWI = \ln(\alpha/\tan\beta)$$

where α is the local catchment area draining through a certain point per unit contour length and $\tan\beta$ is the local slope. The TWI has been used to study spatial scale effects on hydrological processes (Beven et al., 1988; Famiglietti and Wood, 1991; Sivapalan and

Wood, 1987; Siviapalan et al., 1990), to identify hydrological flow paths for geochemical modelling (Robson et al., 1992) and recently for lava flow paths (Cando-Jacome & Martinez-Grana, 2019). For this study, the TWI was calculated from the LiDAR dataset available.

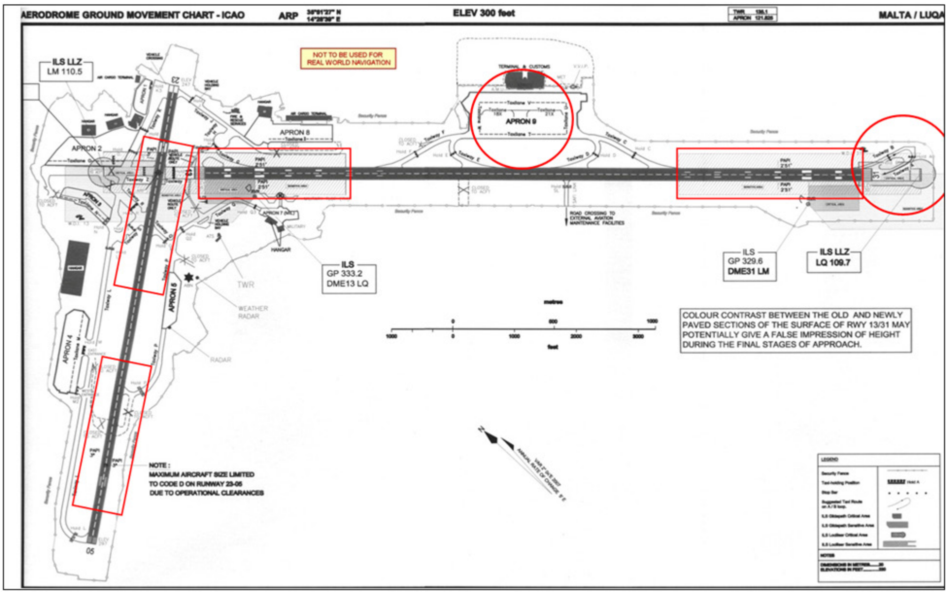
Figure 1 shows a map of the Malta LUQA runway (ICAO: LMML). Runway 13/31 measures 3544 x 60 meters while the shorter runway 05/23 measures 2377 x 45 meters.

Figure 1: Map of the Malta LUQA runways. Coordinates: N35'51.45' / E14'28.65'. Elevation is 297.0 feet MSL. Magnetic Variation is 3° East.



Of particular interest are three main points at Luqa runways, these being: the touchdown and takeoff points along runways 31-13 and 05-23, Apron 9, and TWY A and B at the extreme end of runway 31 (insets in red; fig. 2).

Figure 2: Areas of interest residing within Malta Luqa Airport (ICAO: LMML).

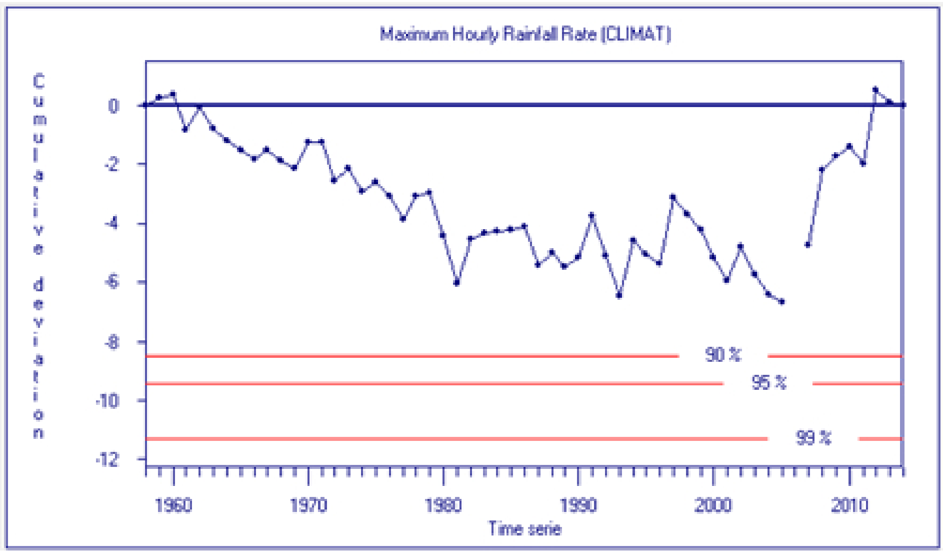


Results

Weather extremes and return periods.

The cumulative deviations from the mean of the maximum hourly rainfall observations for the period 1959-2015 (n=52) are shown in fig. 3. The vertical axis was rescaled and lines presenting various probabilities at which the homogeneity of the data can be rejected are shown. Since the values fluctuated far off from the lines where homogeneity is rejected, the data of the time series is considered to be homogenous (at 99% confidence level) with no breakpoints.

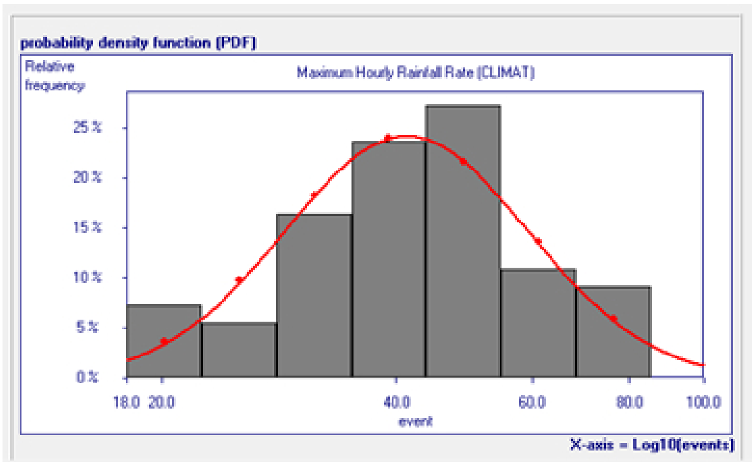
Figure 3: Homogeneity test for the time series of hourly maximum rainfall rate for Malta Luqa Airport (Malta LMML, WMO Climate Station) for the period 1959-2015. Data homogeneity is acceptable at 99% CL. Data for 2006 and 2007 are missing from dataset.



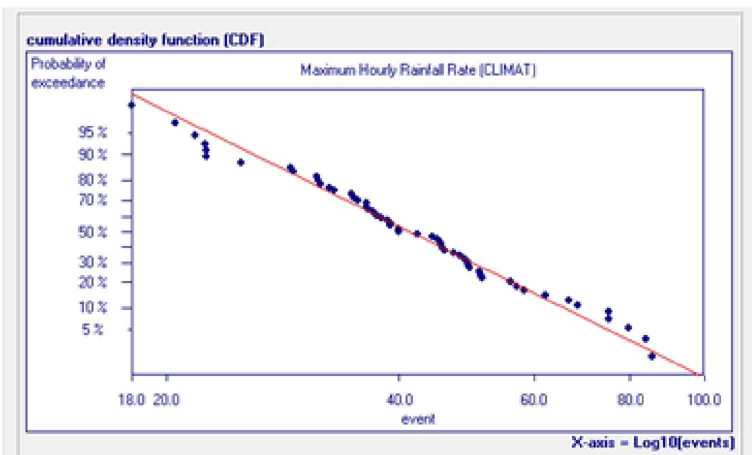
The probability plot (i.e. both the probability density function and cumulative density function) of the maximum hourly rainfall rates versus their probabilities of exceedance is shown below (fig 4a-b). The scale of the event was transformed to log10 for best and most significant distribution at 95% level with an R2 of 0.98.

For example, the extreme rainfall event that occurred in 2012 at Malta Luqa airport showed an hourly rainfall rate of 84 mm hr-1. By plotting the value on the probability plot (fig. 4b), it is evident that the event was one of the highest throughout Malta's record period for this parameter. The return periods of hourly rainfall rate are shown in table 1. Statistically, the return period to reach or exceed the 2012 maximum hourly rainfall rate record is estimated to be around 41 years under current climatic conditions. However, other return periods which can be deemed as significant for the safety of aircraft landing or taking off from Luqa airport are also valid and having shorter return periods. This means that risk of runway flooding is present.

Figure 4a-b: Probability and cumulative functions (PDF and CDF; both significant at 95% level) of the maximum hourly rainfall rate for Luqa Airport (Malta, WMO Climate Station) on log10 probability for the period 1959-2014, with the highest hourly rainfall rate of 84 mm hr-1 recorded during the September 2012 event. Distribution of both PDF and CDF are acceptable at 95% CL



(a) Probability density function of maximum hourly rainfall rate.



(b) Cumulative density function of recorded maximum hourly rainfall.

Table 1 shows the estimated hourly rainfall rate for Luqa Airport (Malta LMML, Climate Station) for selected probabilities and return periods from the probability plot (fig 4a-b).

Table 1: Estimated hourly maximum rainfall rate for Luqa Airport (Malta LMML, Climate Station) for selected probabilities and return periods as derived from the probability plot shown in fig. 4a-b.

Probability of exceedance (%)	**Hourly rainfall rate (mm hr-1)**	**Return period (years)**
1	95.8	100
2	86.8	50
5	74.9	20
10	65.6	10
20	56.0	5
50	41.3	2

The total number of occurrences with solid precipitation (i.e. hail) during the period 1973-2009 is seen to be generally on the decline. The annual records varied between 400 (1974) and 5 events (2004). The average number of hail events for this 37-year period is 155.4 per year. The negative trend (which is significant at 95% confidence level) however, potentially reflects Malta's changing climate, tied to a decreased frequency of solid precipitation over Luqa airport. A shift is also detected in the number of yearly hail occurrence throughout the study period. The homogeneity test shows a clear change of slope in the year 1990. Over the period 1973-1990 the total number of yearly hail events was above normal while over 1991 – 2009, the opposite pattern can be observed. It is important to note that the estimation method remains the same for both periods. This is the best available local data that is available for the occurrence of this meteorological phenomenon specifically derived from Malta Luqa Airport.

The reference period 1973-2009 can be therefore split up into two statistically significant periods which have different means: 1973-1990 with a mean of 265 hail events and 1991-2009 with a mean of 51 events. The jump in the mean between the years 1990/1991 separates the two periods. Based on best probability plot (R2- =0.93), the return periods of occurrences of hail (and therefore a higher probability to record extremes) are shown in table 2.

Table 2: Estimated return period of number of hail events for Luqa Airport (Malta, Climate Station) for selected probabilities and return periods derived from the probability of exceedance plot.

Probability of exceedance (%)	**Yearly occurrence of hail**	**Return period (years)**
1	451	100
2	417	50
5	365	20
10	318	10
20	262	5

The estimated return periods of between 50 and more years must be considered with caution. According to the official definition given by IPCC (2007), climate change is a change observed over a time period of 30 to 50 years or longer, and the time series used to derive the return periods might not contain a strong enough climate signal of such change (what Goodwin & Wright [2010] identified as a 'sparse' reference class for a typically 'chaotic' weather process). Moreover, being based on past values and records, statistically-derived return periods are mathematically possible on the assumption that the variability between past and future data sets remains stationary and that future time series will reveal frequency distributions similar to the observed ones. As the number of observations gradually increases, the error in determining expected return periods diminishes. Overall however, a period of 30 years and over (such as this study) is considered to be very satisfactory for this study.

Locating flood-prone areas on the runway surface.

Following detailed morphometric analyses of LiDAR data, the likely presence of runway tarmac surface depressions that can hold standing water and leading to damp, wet and water patches along extended parts of the runway were identified. These terms in italics are further defined in Annex 6 and 14 of ICAO circular 329. Standing water refers to accumulated water on the runway surface caused by heavy rainfall or by poor drainage as a result of the macro texture, and is regarded as water of a depth greater than 3 mm.

A case in point is the relatively higher value for the TWI as shown in figs. 5 and 6 below. Higher values represent drainage depressions, lower values represent crests and ridges as can be identified from the raster resolution (in this case 1m x 1m; 4 points.m-1).

Figure 5: Higher indices obtained over TWA A towards entry to Runway 31.

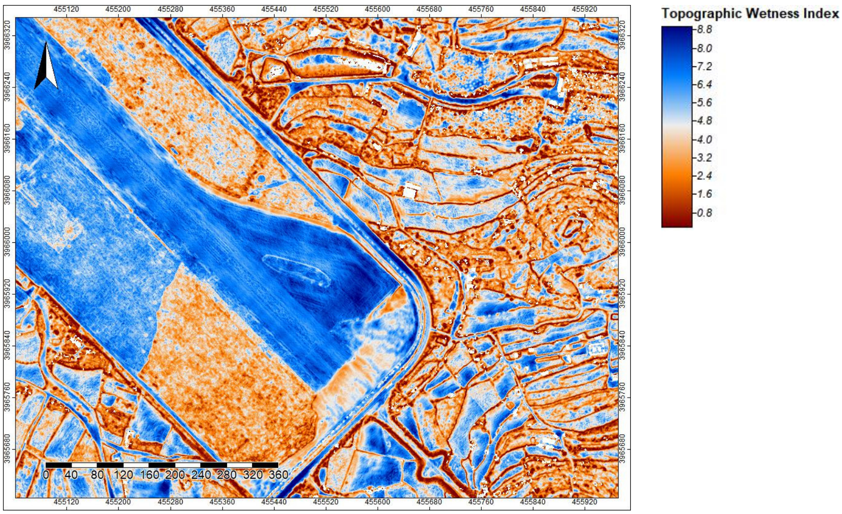


Figure 6: Spatial distribution of the wetness index over Apron 9, in front of terminal building, but towards air side at Malta Luqa Airport.

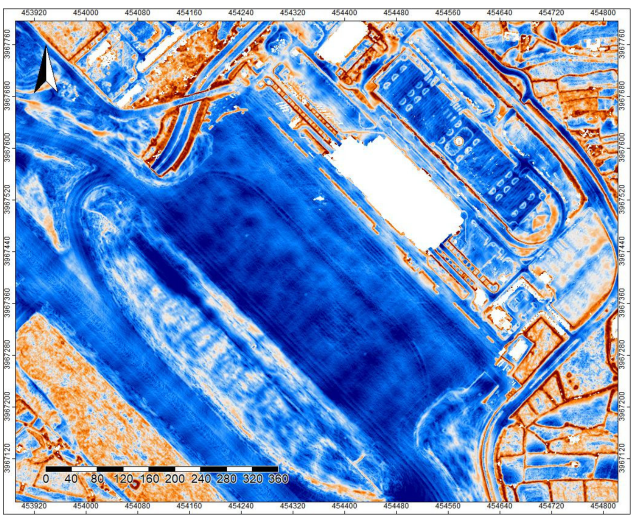
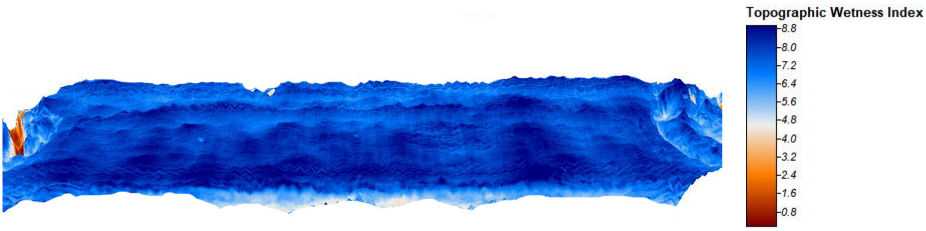


Figure 7 shows a shallow 3D profile of Apron 9 to illustrate the unevenness of this part of the airfield at the time of data acquisition. Areas that appear dark blue have a higher wetness index, which can be translated to deeper depressions within the Apron's surface. Topographic raster data analysis can also easily extract transverse and/or longitudinal profiles to quantify unevenness in both axes (not shown).

Figure 7: 3D profile of the topographic wetness index of Apron 9 as seen from the side.



Other potentially problematic areas within the airfield were identified, including (i) parts of RWY 05 (such as at 451508.302 m E; 3967507.633 m N; 451425.361 m E, 3967646.245 m N), (ii) exit of TWY F onto runway (453753.366 m E, 3967667.832 m N) and (iii) junctions of TWY D onto both runway and Apron 9. These areas could potentially lead to wet surfaces or the occurrence of water patches (standing water). Although these problematic areas were confirmed on the basis of experience, actual onsite verification and measurements are strongly recommended, especially during high rainfall rates.

Since the time of collection of the LiDAR data in 2012, important structural improvements have been made to Apron 9, and new tarmac resurfacing of its sides, including in taxiways have been carried out. The Airport Management has meanwhile upgraded the assessment of the runway water surface conditions by introducing runway flood sensors based on ICAO recommendations. These sensors collect real-time rainfall measurements to establish the runway surface conditions, especially during and after heavy rainfall episodes.

Study limitations

This study does not look at the link between rainfall rate, drainage and texture capacity of the airfield pavement. It merely highlights the fundamental aspects of the first two variables namely – rainfall rate (and return period of extreme events) as well as problematic areas of the airport pavement that might pose problems with water drainage and resulting contamination. Moreover, local rain intensity has been derived from a single rain gauge station located along a Luqa runway and does not provide a precise rainfall rate along different parts of the runway.

Recommendations

Further studies to link rainfall rate with roughness and surface drainage capacity is hereby being recommended in order to establish critical thresholds, which could then become incorporated in risk management protocols for the runway. Parts of the Luqa runway can be subsequently classified based on different drainage characteristics until further improvements to lower risks of hydroplaning are made. The following recommendations are being put forward:

- A number of water depth modelling studies can be carried out (see Benedetto, 2002) that can help managers define timely thresholds of relevance to ATC and flight crews regarding the amount of water present on a runway.
- The Weather radar information available at the Malta Airport MetOffice can be used to assist in this timely warning. However, this is a subject that needs further study.
- Calculate in real time, the safety condition of each landing or taking off, on the basis of runway surface flood water measurements and related conditions.
- Use the climatological information gathered by this study as thresholds of expected critical rainfall events that could make the airport unsafe and include this climatology as part of the safety management of airport pavement.
- The introduction of new measurement and communication technologies on the runway can make possible data gathering and information processing related to the degree of wetness of the runway. This information could be then transmitted instantaneously to all parties concerned such as flight crew, ATC and Meteorological Office. Such a system should also be capable of ATIS integration, thus eliminating weak points of communication through ATC.
- Conduct periodic LiDAR surveys and calculate the spatial topographic wetness index of the airport pavement to assess in a holistic and quick way, the state of unevenness of the runway and to highlight problematic areas without delay.

Conclusion

When an aircraft lands and brakes on a wet runway, the skid resistance drastically decreases under such conditions since the action of braking it strongly dependent on the depth of the water layer residing over the runway at that point in time. Moreover, the loss of contact between the tire and the pavement increases with aircraft speed, which can extrapolate to a zero-friction force, especially during takeoff. These are two of the most critical aircraft maneuvering on the runway.

From both weather and climatology point of view, rainstorm intensity is statistically correlated to the rainstorm duration and to the return period at the site of observation. This study illustrates these two events for Malta Luqa Airport, in terms of absolute values and return periods, within a hazard analyses framework for the Airport. In this sense the return period of particular hazards plays a fundamental role for Airport safety management.

Moreover, this study provides excellent insight on the exposure of local runway infrastructure to wet/flooded conditions due to climatic conditions with all the more reason to assure proper water drainage on the runways.

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CHAPTER 2

Copernicus land monitoring service (CLMS) data – applicability to Malta

Elaine Sciberras

Keywords

CLMS, CLC+, land cover, land use, spatial data, public authorities

Introduction

Copernicus is the EU's flagship program for Earth observation based on satellite observations and in-situ data. The objective of Copernicus is to monitor and forecast the state of the environment on land, sea and in the atmosphere, to support climate change mitigation and adaptation strategies, the efficient management of emergency situations and the improvement of the security of every citizen (European Commission, 2022a). Satellite observations are derived from a suite of dedicated satellites called 'Sentinel' and contributing missions for higher resolution imagery (ESA, 2022).

Copernicus is a user driven programme, for which its data and information services are available to users, mostly public authorities, on a full, open and free-of-charge basis. The European Commission manages the Programme. It is implemented in partnership with the Member States. The European Space Agency (ESA) is responsible for the space component, whereas the service components are implemented the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF), the European Environment Agency (EEA), Mercator Océan and EU agencies. (European Commission, 2022b). The satellite and in-situ data are used to develop a wealth of value-added information through six thematic streams of Copernicus services:

Copernicus Atmosphere Monitoring Service (CAMS)
https://atmosphere.copernicus.eu/
Copernicus Marine Environment Monitoring Service (CMEMS)
https://marine.copernicus.eu/
Copernicus Land Monitoring Service (CLMS)
https://land.copernicus.eu/

Copernicus Climate Change Service (C3S)
https://climate.copernicus.eu/
Copernicus Emergency Management Service (CEMS)
https://emergency.copernicus.eu/
Copernicus Security Service (CSS)
https://www.copernicus.eu/en/copernicus-services/security

These Copernicus services transform satellite and in situ data into value-added information by processing and analysing the data. Maps are created from satellite imagery, features and anomalies are identified and statistical information is extracted. Each services produces value-added outputs specific for the respective theme. Such data and information are then used by service providers, public authorities, and international organisations to improve the quality of life for citizens of Europe and around the world and to monitor and mitigate climate change. The availability of datasets extending back for years and decades, enable time-series analysis to be carried out. This enables monitoring of environmental changes whereby patterns can be examined and used to create better forecasts, for example, of the ocean and the atmosphere. Maps are created from imagery, features and anomalies are identified and statistical information is extracted (European Commission, 2022a).

At a national level, the CLMS is one of the services which has been taken on board by public entities due to the monitoring aspects of land cover and land use. The CLMS is the focus of this paper and will delve into the products at pan-European and local level, as well as the current state of play at a national level.

The Copernicus Land Monitoring Service

The Copernicus Land Monitoring Service provides geospatial information on land cover (LC) and its changes, land use (LU), vegetation state, water cycle, cryosphere, and earth surface energy to a range of users in the field of environmental applications. It supports environmental and development policies, as well as applications in domains such as spatial and urban planning, forest management, water management, agriculture and food security, nature conservation and restoration, rural development, ecosystem accounting and mitigation/adaptation to climate change (European Commission, 2022c).

Land cover corresponds to a (bio)physical description of the earth's surface. It is that which overlays or currently covers the ground. This description enables various biophysical categories to be distinguished - basically, areas of vegetation (trees, bushes, fields, lawns), bare soil, hard surfaces (rocks, buildings) and wet areas and bodies of water (watercourses, wetlands) (EEA, 2022e).

Land use corresponds to the socio-economic description (functional dimension) of areas: areas used for residential, industrial or commercial purposes, for farming or forestry, for recreational or conservation purposes, etc. Links with land cover are possible; it may be possible to infer land use from land cover and conversely. But situations are often complicated, and the link is not so evident. Contrary to land cover, land use is difficult to observe. For example, it is often difficult to decide if grasslands are used or not for agricultural purposes. Distinctions between land use and land cover and their definition have impacts on the development of classification systems, data collection and information systems in general (EEA, 2022e).

The CLMS delivers products on global, pan-European and local products which are of relevance to Malta. The pan-European component is coordinated by the European Environment Agency (EEA) and produces a range of products dealing with land cover (Table 1). The EEA is the EU agency tasked with providing reliable, independent information on the environment. Its mandate is to help the EU and Member States make informed decisions about improving the environment, integrating environmental considerations into economic policies, and moving towards sustainability. The EEA also coordinates EIONET, the network of national environmental bodies set up to help the EEA (EEA, 2022f).

Table 1: Range of available CLMS products at pan-European and local levels (EEA, 2022a, 2022b)

Level	**Product**	**Description**
Pan-European	CORINE Land Cover (CLC)	• Land cover and land cover changes vector maps. • Available for 1990, 2000, 2006, 2012, and 2018. • CLC layers - Minimum Mapping Unit (MMU) of 25 hectares (ha) • CLC change layers - MMU of 5 ha

	CLC+	• 2^{nd} generation CLC: • CLC+ Backbone (BB) raster and vector product) • database/web application component (CLC+ Core) • LC/LU products ("Instances"), on a 100m grid level
	High Resolution layers (HRLs)	• Raster maps for different land cover characteristics. Most HRLs available for HRLs are available for 2006, 2009, 2012, 2015 and 2018. • Characteristics include imperviousness, forest, grassland, wetness and water • Latest versions available at 10m resolution.
	Biophysical parameters	• Maps of bio-geophysical products on the status and evolution of the land surface • Currently two products are implemented: 'High Resolution Vegetation Phenology and Productivity' and the 'High Resolution Snow and Ice monitoring'.
	European Ground Motion Service (EGMS)	• information regarding natural and anthropogenic ground motion millimetre accuracy • Full portfolio available since Q3 2022
Local	Urban Atlas	• comparable land cover and land use data for specific Functional Urban Areas (FUA) as major EU cities. • Available for 2006, 2012, 2018 • Change layers available for 2006-2012; 2012-2018
	Riparian Zones	• Land cover and land use in areas along rivers • MMU of 0.5 ha

	Natura 2000 (N2K)	• LC/LU maps in a selection of grassland rich sites to assess such sites are being effectively preserved and if a decline of certain grassland habitat types is being halted • Reference years: 2006, 2012 and 2018 • 2 km buffer zone around each Natura 2000 site • MMU of 0.5 ha
	Coastal Zones	• LC/LU product maps with a 10 km landwards buffer • Reference years: 2012 and 2018 • Change layer for 2012-2018

The CLC+ generation of products is one which is currently undergoing significant developments in terms of new outputs (Figure 1). The CLC+ Backbone, as first component of the upcoming CLC+ era, is geospatial data component. It features an object-oriented wall-to-wall high-resolution inventory of European land cover for the reference year 2018. It will consist of a pan-European combined "hardbone" and "softbone" segmentation of vector-based stable landscape objects and a raster-based classification of 11 EAGLE compliant land cover classes at 10m spatial resolution. Vector and raster datasets will be fused into a fully attributed, 18 land cover class, vector product with 0.5 ha minimum mapping unit (MMU), additionally incorporating a multitude of further information layers derived from satellite data and various other Copernicus products (Probeck et al., 2021). The CLC+ Core, a database/ web application component, will act as a tool to create tailor-made 100m grid products (instances) by combining available data in new ways. It will deliver a consistent multi-use grid-based LC/LU hybrid data repository. Through such an approach, the CLC+ Core will incorporate existing and future European CLMS products and various national LC/LU products using a standardized integration approach in line with the EAGLE data model (EEA, 2022c). This approach is one which is expected to be taken onboard by respective national entities in Member States.

Hardbone represents a geometric skeleton of persistent linear landscape objects such as transportation network (e.g. roads) and hydrological waterways (e.g. rivers, lakes, canals) and therefore consist of various line vector data.

Softbone further delineates landscape objects in a controlled automatic manner based on an image segmentation technique carried out by the EEA. This generates landscape object polygons by their spectral response and variation throughout a year within the frame of the hardbone data.

Figure 1: CLC+ Product Suite

Source: (EEA, 2022b)

Through a dedicated online repository, entities can upload LU/LC from the CLMS and national inventories to be ingested into CLC+ Core, and individual classes will be captured as elements of the EAGLE data model. These elements are separated into 3 components:

- land cover components (LCC)
- land use attributes (LUA)
- further characteristics (CH)

The aim is that these components will allow users to derive tailor-made LC/LU products (so called "Instances"), on a 100m grid level, based on an on-demand combination of available (EAGLE harmonized) LC/LU information. This will allow the combination of previously non-harmonized datasets in new ways, in particular LC information coming from CLMS products with specific land use information from the countries (EEA, 2022b).

Spatial information and the availability of Maltese datasets within the public administration

In recent years, an awareness on the use of spatial data within the public administration has been given importance and enabled the investment in high-end technology for data capture. The concept of digital transformation and the contribution towards EU's digital strategy (European Commission, 2022a) are key elements for pushing the digital drive in the field of Geomatics. Spatial digital technologies are instrumental in providing knowledge and driving policies related to issues such as the EU's Green Deal (European Commission, 2022b), the European Commission's Space Strategy for Europe (European

Commission, 2016), the European Environmental Agency's (EEA) reliance on spatial data for land monitoring (Jensen, 2014), the European Spatial Planning Observation Network's (ESPON) formulation of territorial development policies (ESPON, 2022) and monitoring the UN's Sustainable Development Goals (SDGs) (UN, 2022). The various applications of spatial data have enabled Maltese government entities to make use of geomatic data for their respective requirements.

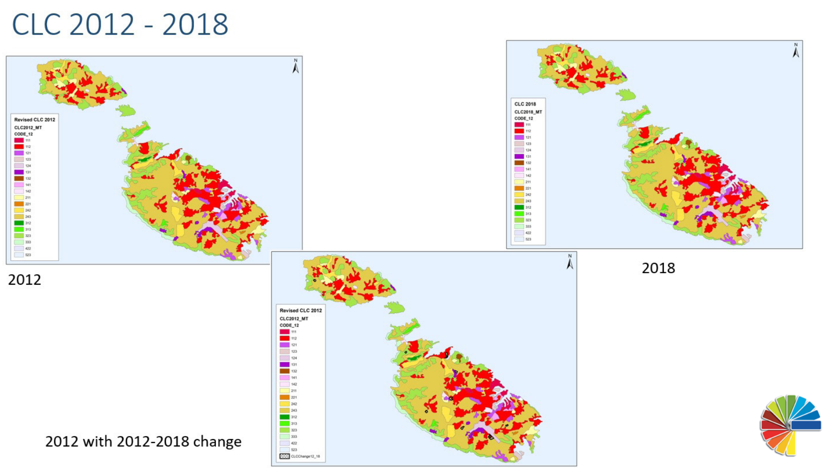
An overview of the Malta INSPIRE MSDI geoportal (Planning Authority, 2022a) and the SIntegraM geoportal (Planning Authority, 2022b) provide good examples of the applicability of digital mapping, Geographical Information Systems (GIS) and remote sensing in over twenty local government entities. Apart from the collation of public administration geodatasets in such a portal, several entities provide geoportals with specific spatial datasets whereby data can be viewed, downloaded and analysed to varying extents. Examples include the Planning Authority's (PA) MapServer (Planning Authority, 2022c), the Environmental Resource Authority's (ERA) Malta Environment Platform & Services (MEPS) (ERA, 2022), Transport Malta's geoportal (Transport Malta, 2022) and Parks Malta – Valley Management Unit's IP RBMP Geoportal (Parks Malta, 2022).

Nonetheless, the use of satellite imagery and its added-value datasets within the Maltese public administration is somewhat limited. This is particularly so in terms of Copernicus service datasets. Indeed, the INSPIRE MSDI geoportal and the PA's Mapserver seem to be the local resources from which local Copernicus data is accessible. Nonetheless, all Copernicus CLMS datasets noted in Table 1 for Malta area directly accessible from the EEA CLMS portal (EEA, 2022a, 2022b). The University of Malta developed a web platform - Malta Copernicus Marine Service Platform (CMS, 2022) - to provide information on key marine parameters in the Maltese coastal areas from observations and numerical models. This aims to serve local users, including government entities, with online access to dedicated products and services derived from the Copernicus Marine data.

CLMS data – the Maltese scenario

The limited user uptake of the Copernicus service data in Malta, in particular CLMS data, is likely to be due to the spatial resolution of the respective datasets. With the Maltese Islands having a total surface area of 246 km^2, there is a need for high resolution spatial data to understand and analyse the detailed change in land cover over such a relatively small surface area. In this respect, Malta is one of a few Member States which is unique in its status as a small island state. The low MMU of CLC datasets (Table 1) results in an over-generalisation of the respective LC classes (Figure 2). This implies that such datasets remain indicative for the local Maltese context and would rarely be used for the formulation of local policies. The EEA's general concept behind the CLC datasets was to obtain harmonized LC classification across all Europe at the same map scale. Consequently, the output for Malta is generalised. As Malta's National Relay Contact (NRC) on the EIONET's land cover/land use group, the Planning Authority was involved in the production and verification of both CLC and HRL datasets. Since the EEA's inception of the CLC datasets, Malta has to date contributed to five CLC runs, namely 1990, 2000, 2006,2012 and 2018, and four change layer maps for 1990-2000, 2000-2006, 2006-2012, and 2012-2018 (Planning Authority, 2022a).

Figure 2: CLC maps for Malta for 2012, 2018 and respective change layer map



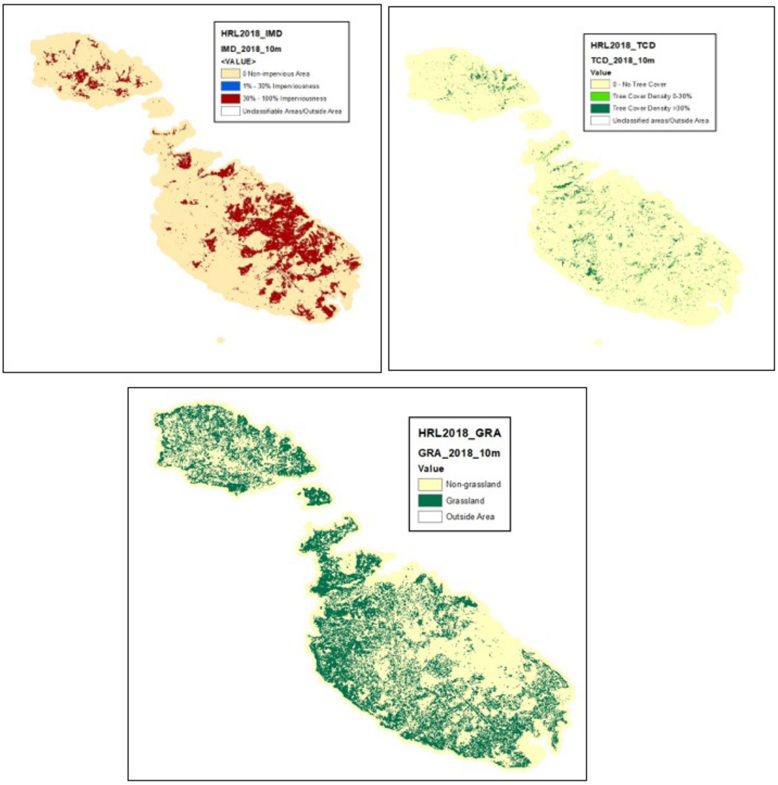
Source: EEA, 2022a

On the other hand, due to the advancement in the technology of the Copernicus' Sentinel-2 satellites, HRL products have increased in resolution to 10 meters for the 2018 products, thereby following the source resolution of the Sentinel-2 imagery (EEA, 2022d). Therefore, such higher resolution datasets can be of greater use to the Maltese scenario. To date, the HRL maps derived for 2018 are available for the following land cover types: imperviousness, forest, grassland, wetness and water, and small wood features. External verification of these HRL outputs is required by Member States once they are published on the EIONET portal for registered EIONET users. Malta was required by the EEA to download and verify specific HRL 2018 datasets (Table 2). As NRC for land cover, this project was carried out by the Planning Authority. An overview of some of the HRLs available for Malta for 2018 are provided in Figure 3.

Table 2: HRLs available for 2018 which were verified for Malta in 2021 (EEA, 2022d).

HRL Product Name	**Status Layer**	**Description**
Imperviousness	Imperviousness Density (IMD)	• percentage of sealed area • Available as 10m spatial resolution (2018) and aggregated 100m products
	Impervious Built-up (IBU)	• areas of the sealed surfaces where buildings can be found • binary product expressed as built-up or non-built-up
	Imperviousness change (IMC)	• percentage of sealing increase or decrease for those pixels that show real sealing change in the period covered • 20m and 100m
Forests	Tree cover density (TCD)	• level of tree cover density in a range from 0-100% • 10m and 20m resolution
	Dominant leaf type (DLT)	• broadleaved or coniferous majority • 10m resolution
	Dominant Leaf Type Change (DLTC)	• masking lost or new leaf type cover for 2015 – 2018 • 20m resolution
Grassland	Grassland (GRA)	• binary status layer mapping grassland and all non-grassland areas • 10m resolution
	Grassland Change (GRAC)	• Grassland change 2015-2018 (GRAC1518) which distinguishes new grassland, loss of grassland, as well as unverified loasses and gains • 20m resolution
Water and Wetness	**Water and Wetness (WAW)**	• defined classes of (1) permanent water, (2) temporary water, (3) permanent wetness and (4) temporary wetness • 10m resolution

Figure 3: HRLs 2018 available for Malta for IMD, TCD and GRA



Source: EEA, 2022d

External verification of HRLs by Member States involves expert knowledge of both the HRL products and the national territory using in-situ reference data. In fact, the EEA relies on Member States' reference data and expert knowledge to provide a detailed assessment of the HRLs produced by the EEA. In the case of HRLs 2018 verification by Malta, the in-situ reference data involved national orthophotos for 2016 and 2018 (Planning Authority, 2022c), Google Earth Street view, the Article_17_Habitats_Map for 2019 (Planning Authority, 2022c) and the respective 2015 HRLs. Verification involved both a qualitative and a quantitative process (EEA, 2021a). In the former, a rigorous comparative overview of each HRL dataset is carried out by cross-checking areas with in-situ data – an exercise called the 'look and feel' verification. This resulted in a list of commission and omission errors whereby the respective land cover was not classified correctly. For the quantitative process, a statistical verification analysis was also carried out for HRLs using a methodology provided by the EEA to EIONET users. This involved a stratified sampling approach and resulted in percentage user accuracy values for each HRL.

It should be noted that HRLs published by the EEA and available for download to users (EEA, 2022d) are the datasets which have been externally verified by Member States. Once verification reports are officially submitted to the EEA, the respective online datasets are not updated. Details, statistical analysis and recommendations are taken into account by the EEA when producing the future set of HRLs.

CLMS future products and challenges – the Maltese scenario

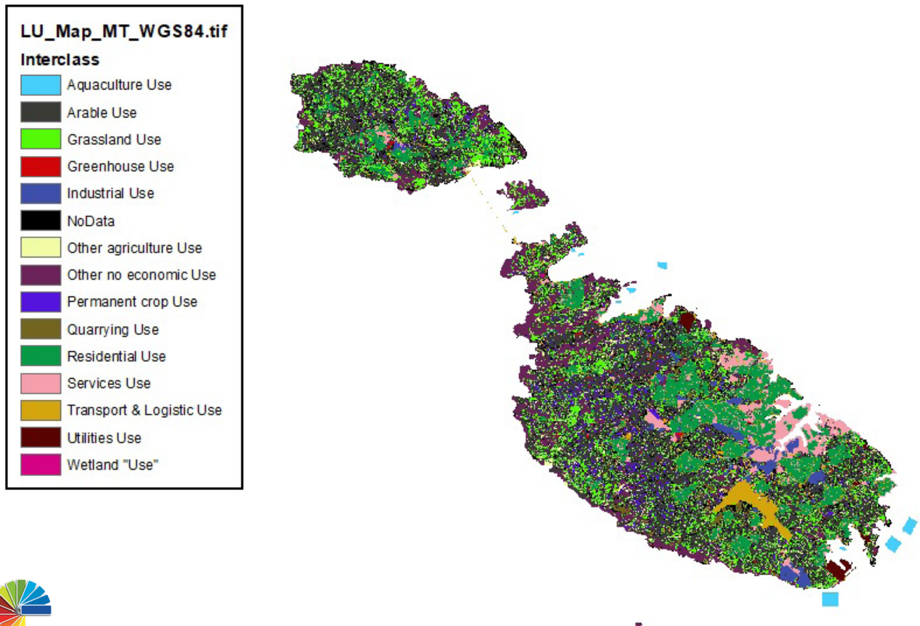
The development and implementation of the new CLMS series of products and applications, the CLC+ system, is expected to bring interesting and useful outputs in the field of LULC. The EEA expects that the CLC+ will become part of the new European baseline for LC/LU monitoring for the decade to come with 'instance' datasets aimed to support to key EU policy needs through the full policy cycle, as well as to specific needs as expressed by stakeholders in Member States. The first use-cases for CLC+ Core instances are expected to deal with monitoring, reporting and validation to support the implementation of the Regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry (LULUCF) (EEA, 2022a). The technologies and respective methodologies required to product such outputs by Member States present a challenge to Member States. Expert knowledge of the territory as well as experience in past EEA land cover work is key to enable Malta to continue its work on the CLMS. Furthermore, land cover datasets require in-situ data from various sectors such as agriculture, grassland, inland waters and infrastructure. This implies that data sharing of existing datasets by the respective entities is crucial for a national effort in the production and verification of the CLC+ products.

This will be particularly the case with the upcoming production of new EEA HRL datasets and their subsequent verification by Member States. These new HRL products include new datasets on crop products, such as crop type, crop diversity and fallow land, new grassland products such as herbaceous cover, and a new forest product on vegetation disturbance, all at 10m resolution.

With the development of the EEA-EIONET Strategy 2021-2023 (EEA, 2020), as part of the new EIONET Land Systems Group from 2022, the PA will continue to oversee the verification and analysis of the future CLC suite, especially the second generation

CLC+ products. To date, one of the products to be developed nationally as part on the development of the EEA's LULUCF instance, was the creation of a comprehensive land use attribute (LUA) map for Malta (Figure 4). Land use classes (Figure 5) and class priorities were designated by the EEA for the purpose of the LUA map production.

Figure 4: Land Use Attribute (LUA) map derived by the PA as part of the development of the EEA's LULUCF instance.



Source: Planning Authority (2022)

Figure 5: LUA classes and class priorities as designated by the EEA for production of the LUA output.

Level-1	Priority	Level-2	Priority
Agriculture Use	2	Arable Use	2
		Grassland Use	3
		Permanent crop Use	4
		Agroforestry Use	5
		Greenhouse Use	6
		Other agriculture Use	7
Forestry Use	1		1
Mining and quarrying Use	5		16
Urban Use	4	Industrial Use	12
		Services Use	13
		Transport & Logistic Use	14
		Utilities Use	15
		Residential Use	11
Water Use	3	Aquaculture Use	9
		Other water Use / No economic Use	10
Other Ecosystem Service Use / No Economic Use	6	Wetland "Use"	8
		Other no economic Use	17

Source: EEA, 2022b

The EEA's intention was that such a LULUCF LUA layer is a set of LU information that facilitates use (i.e. ingestion and further use in CLC+ instances) for LULUCF. It is not meant to be standalone EEA/CLMS product. Nonetheless, the LUA output provided a positive example of cross-entity collaboration to derive a product of various thematic classes and that is of national interest. Since data classes pertained to agriculture, quarry, urban use and wetlands, the LUA was built on various in-house datasets derived from the PA, Environmental Resource Authority, Transport Malta and Agriculture (ARPA) Department.

Conclusion

The CLMS product line acts as an important repository of land cover, and future land use datasets at a national level. Nonetheless, the varying spatial resolution of the outputs will define the level of user uptake of such datasets both at a public administration level and for research purposes. The HRL datasets at 10m resolution have potential for spatial applications at a national level whereas outputs at 100m resolution can be used largely as an indicative level. The second generation CLC+ outputs will provide more data rich information. This will be particularly so with the potential for ingestion of national and EU datasets to extract user-defined datasets to investigate specific CLC+ instances. The increasing complexity of such CLMS products and services poses a technical challenge requiring national CLMS expertise to use the information available correctly. Therefore, it is necessary that production systems are streamlined for easy access of data and sufficient training opportunities are provided to Member State public authorities. This would help to maximise the creation of value-added information from CLMS products for spatial modelling and policy making.

CHAPTER 3

Taking LiDAR to Court: Mapping vapour evidence through Spatial Forensics

Saviour Formosa

Keywords

courts, unmanned aerial vehicle (UAV), terrestrial laser scanner (TLS), GIS, courts, crime scene recreation, WebGL, crimemalta.com, www.cloudisle.org

Introduction

Introducing a new methodology in a traditional and conservative domain averse to technology is never a Euclidian straight-line process. The path is winding, requiring years to prepare, convince non-technical professionals such as the courts and eventually present the findings. Spatial Forensics is a scientific process aimed at the study of the data cycle pertaining to a crime scene. The design, capture, cleaning, analysis and presentation of the results in a Court of Law requires solid theoretical, factual and methodological protocols steeped in the science of data.

The term vapour evidence points to the volatility of the crime scene data that is governed by a time-restricted period within which forensic experts need to work in before the evidence deteriorates or requires removal. Scientists and Scene of Crime Officers (SOCOs) work within very short periods and require quick scene capture. Long dependent on camera-based photos and video capture, the introduction of unmanned aerial vehicles (UAV), terrestrial laser scanners (TLS), infrared cameras, LiDAR (Light Detection and Ranging) and GPR (ground penetrating radar) capture technologies have enabled a rapid response approach. Other mobile technologies such as robot devices (legged quadrupeds and caterpillar tracked devices), remotely controlled technologies and space-based systems have served the forensics enhancement such that in conjunction with GIS (geographical information systems) and 3D immersive technologies, the integrative aspects of the hardware-software-content domains enable the recreation of crime scenes such that their presentation in court is gaining acceptance. Issues plaguing witness recollection would consequently be reduced or eliminated due to the immersive outputs that would allow them to visualize the scene during juries that might take place months or years later, impinging on memory and recollection. The scope of the spatial forensic approach is to serve a multiplicity of tasks:

- as a triggering medium for witnesses as a recollection tool;
- as a reconstruction of what the scene was like during the incident;
- as a replica for juridical and prosecution-defence dynamics;
- as positing the ability to move the crime scenes to the courtroom or the investigators' work arena during the initial part of the case;
- as a tool to juxtapose the scene onto real ground years after the case when the real space crime zone would have been altered due to development, societal change and environmental changes; and
- as a preparedness tool that pre-capture hi-risk zones in case of future incidents such as fireworks factories.

This chapter explores the processes employed to take LiDAR to court, presenting the steps undertaken and posits cases upon which the processes were introduced in the Maltese Islands.

Note

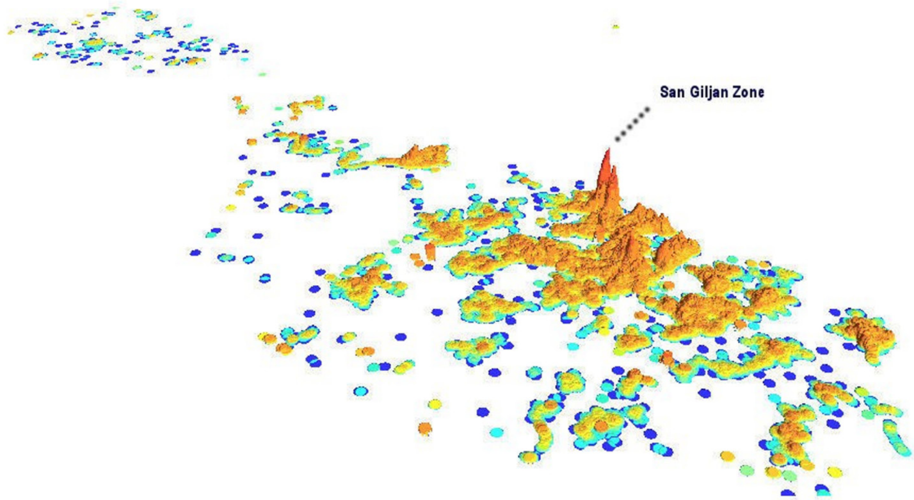
Acknowledgments are due to The Malta Police Force Forensics Laboratory, through Inspector Charlot Casha and his Team of experts.

Theoretical constructs

Crime scene capture lives in a multi-dimensional construct dependent on complex but easily understandable theoretical approaches. However, the study of spatial forensics is not new. From the early non-technological era of the 19th Century to early 20th Century studies on crime mapping through the work in environmental criminology theory, also known as the geography of crime or the ecology of crime (Maguire et al, 1997) and on the offshoots of the Chicago School, through the study of spatio-temporal crime (Shaw and McKay, 1942). These studies rest on even earlier studies on the recogniton of comparative visualistation as a tool to study forensics. Spatial research has a long history where the earliest attempts at analysing crime through spatial patterning can be traced back to several nineteenth century innovations. In Belgium, Adolphe Quetelet (in 1835) and in France, A.M. Guerry (in 1833) made use of maps together with studies of urban-rural and crime/socio-economic conditions relationships (McLaughlin et al: 2001, 133), followed by Henry Mayhew in 1861 who published maps of England and Wales outlining the 'intensity of criminality' (Kelley, 1967).

Fast forward to the present, the need for information systems that cater for specific areas of study has long been felt, particularly in the attempts to identify crime patterns through the use of wall maps and coloured pins. Even before the advent of computing, researchers identified that the main point of contention with this methodology was that few persons could effectively identify trends based on variables such as crime type, time and relationship to other crime locations (Argun et al, 2016). The technology was very basic and limited and progressively needed other methods such as flash card, catalogues, calculators, spreadsheets or databases to cater for the research demands. This brought about a need to develop digital spatial information systems, better known as GIS. Technological upheavals, mainly GIS, has enabled the progress to capture crime data from a passive mode (Figure 1) to a real-time mode, whilst retaining the tenets of criminological theory.

Figure 1 shows what was depicted as a 3D map of the extent to which Paceville vehicle related crimes in the mid-1990s peaked in very small cluster of roads.



The crime scene reconstruction approach builds on multi-domain theoretical approaches. These include the concept of spatial reasoning and locational choice (Varzi, 2007) as a process to conceptualise reality based on location whilst the expansion of the hierarchical spatial reasoning focuses on the aggregations of the spatial data into understandable zones, such as boundaries (Weng et al, 2008; Yang et al, 2010). In turn, visual comparative visualisation focuses on conceptualising information (Jaichandran et al, 2021) and data in a visual 3D spatial cognitive approach (Yoon et al, 2015) and on multidimensional models of perception and cognition (Ashby, 1992; Spies, 2005; Spies, 2022). In terms of external validity as against laboratory experiments (Richardson et al, 2009; Egami et al, 2022), GIS is paramount as spatial forensics basis its study in based on external validity for the data cycle and laboratory outputs for the dissemination practices. The next aspect of spatial theories includes spatial information theory (Edwards, 1997; Camara et al, 2001; Goodchild, 2001) and model-based spatial modeling (Şen, 2016; Liu et al, 2019). In terms of statistical analysis, spatial forensics basis its focus on spatio-temporal conceptualization (Zhu et al, 2008; Klippel et al, 2012; Ghazouani et al, 2016), spatial distribution and nearest neighbours (Cox, 1983; Mesarcik et al, 2022) and the spatial-statistical approach (Helbich et al, 2017; Anselin, 2000).

Sourcing the Content

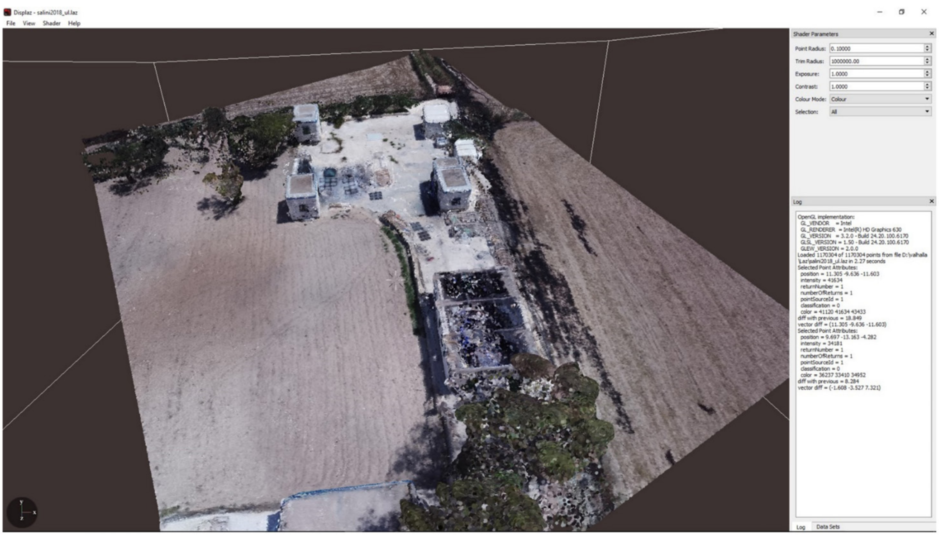
Incident and crime related spatial studies cover various domains, notably on road traffic accidents (Topolšek, 2019; Pádua et al, 2020), UAV and AI in forensic investigations (Renduchintala et al, 2019; Sharma et al, 2019), disaster risk (Garnica, 2021), in-situ body documentation (Urbanová, 2017), forensic image analysis (Verolme et al, 2017), inaccessible places (Obanawa et al, 2014), and targeting accuracy (Abdulrahman et al, 2014). Crime scene reconstruction-specific studies include documentation (Maksymowicz et al, 2010), methodology (Nordby, 2012), 3D modelling (Flor, 2011), scene scanning (Wang et al, 2019), forensic engineering (Knox, 2010), virtuality (Feng et al, 2010), immersive technology (Manelli et al, 2022).

Sourcing the Protocols

This paper covers the processes employed in understanding the capture of a crime scene using examples from experience garnered through the building of a methodology implemented during various incident and crime related scenes that the author investigated. The use of diverse technologies, hardware and software and spatial information systems operating procedures enable the development of various steps and protocols that spatial forensic analysts. Well aware of the limitations impinged through technological, methodological and human factors, due to the sensitivity of the scenes, researchers abide by various data cycle protocols as well as adhering to GDPR requirements.

The scope of the scene reconstruction process is to ensure reliability and validity during the data capture process and ensure that in reconstructing the scene, verification protocols are in place. This is extended to the process used to build a 3D model of the scene for strategic, operational and tactical use. These scenes would also be used for cases such as Disaster Victim Identification preparedness and case review. A preparedness example could include the strategic scanning of highly dangerous infrastructure such as fireworks factories (Figure 2) as a case study to operationally prepare fire crews and paramedics as well as SOCOs to preview the site prior to entry in a post-incident scenario. Thus, their subsequent visuals or immersive scenes can be prepared prior to entry and tactical intervention. Through 2D (crimemalta.com) and 3D immersive virtual environments (cloudisle.org), an output is derived that posits measuring tools online through a normal web-browser. This enables first responders to push spatial data towards the open-source and readily available tools, away from those requiring proprietary tools and access rights.

Figure 2: Fireworks Incident Scene Reconstruction



Technologies Employed

Spatial Forensics is dependent on technologies oriented towards the nature of the crime scene. Outdoor crimes such as environmental crimes, urban and rural open spaces can be captured using UAV (Unmanned Aerial Vehicle) and Laser Scanning technologies, as well as TLS (Terrestrial Laser Scanner). The technologies employed included aerial systems inclusive of DJI Mavic Pro 2 AUV (imagery – Figure 3), DJI Mavic2 Enterprise (imagery and infrared), DJI Phantom 4 Pro (imagery), DJI INSPIRE (imagery), DJI M200 (imagery, infrared) DJI M600 Pro (imagery, infrared, GPR), and a RiEGL RiCOPTER (LiDAR, imagery, infrared). More recently a Unitree Go1 Ai Pro Robot was acquired for scanning in difficult areas such as tunnels and caves, which aided the earlier Faro Freestyle Handheld scanner (Figure 4) and the DJI Osmo.

Figure 3: UAV based pointcloud

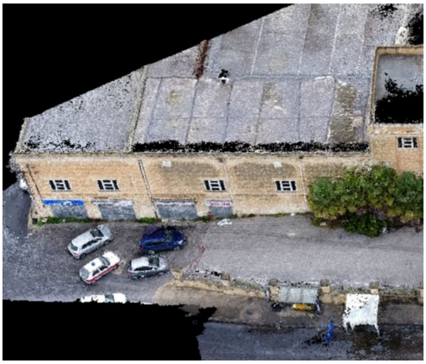


Figure 4: Handheld Laser scanner

In terms of terrestrial and mobile technologies, the researchers used a RiEGL VZ400i Terrestrial Laser Scanner (LiDAR, imagery) and a GreenValley LiBackpack50 (LiDAR) as well as the RiEGL Vehicle-based VMX-2HA system (LiDAR, imagery). Access to a bathymetric Gavia AUV (autonomous underwater vehicle and a tethered QYSEA FIFISH V6 Underwater Robot.

Software used in the study included Reality Capture, Zephyr 3D, Agissoft Metashape, Pix4D, Lidar360, RiScanPro and RiProcess. Output software that was used for scene reconstruction and immersion analysis include Unity 3D and the MagicLeap applications, whilst the WebGL outputs were published using LasPublish as published on www.cloudisle.org.

Methodological Imperatives

As the scope of the remit in spatial forensics is to identify the location of the diverse crime scenes and gather information about on-the-ground spatial location, such was carried out through diverse methods. Such include the identification of data anchored to a georeferenced map, the location of points of interest (POI), the gathering of information using remote and in-situ devices, the employment of software that recreates the location in 2D space through GIS and 3D space using GIS and 3D enabled tools, the use of software that analysis the datasets gathered and that which converts the scene into a 3D format either as a meshed version, a printable version or a WebGL version, the latter allowing for measurements and online calculations, whilst the former allows for visual immersion and tactile renditions.

The verification of area and POI location from various base data sources (imagery, national and international data captured through satellites or UAVs) serve as a basis for local visualisation. National datasets could include LiDAR captures such as those captured in 2012 and 2018 emanating from the ERDF156 (PPCD, 2014) and SIntegraM (European Commission, 2020) projects, subsequent updates using UAV technology such as the 2020 Gozo base-map update, orthoimagery and international data includes satellite imagery available through diverse sources such as Copernicus (Copernicus, 2022). The availability of Ground Control Points (GCPs) also allows for the anchoring of the dataset to a projected map. As crime scenes occur in a real space, the need to anchor that scene in a digital version of that space is vital for accuracy and precision in the analytical process, particularly in the phase that strives to understand the spatial dynamics of how a crime occurred. Thus, such a process requires that the main POIs were identified and recorded, and that the researcher ensures acquisition of the GPS coordinates of the main POIs.

The gathering of information from remote and in-situ sensing devices is required as it serves to actuate the spatial location as well as allowing for a photogrammetric or laser-based capture of the scene. Technologies used to date by the researcher include handheld imagery capture using cameras and videos, UAV-based cameras, infrared cameras, handheld and terrestrial laser scanners, vehicle-mounted mobile laser scanners as well as UAV-mounted laser scanners. Other devices such as ground penetrating radar (GPR) are employed as dependent on the case under investigation.

The methodologies used for the main crime scenes followed a process developed by the author which is based on the following processes:

Remote GPS capture

Locating the exact spatial coordinates of the main POIs from a remote location should the site be inaccessible such as below a cliffside or on a remote island/rock. Such is necessary since GPS readings are displaced in such locations as cliff bottoms and due to the need to acquire the spatial points employing high-end technology. An IkeGPS scanner was used to identify the exact points from a number of main points of interest which would serve as three triangulation points. This method solves the issue of spatial acquisition of remote sites though one must be careful that if used in narrow spaces, the user's GPS location might be compromised due to lack of an adequate number of satellites being acquired by the data or imagery capture device. Such can be overcome through the identification and calibration of the data to multiple GI remote and ins-situ locators such as access to more than 12 satellites, a GNSS network, a network of GCPs and other local or international systems.

Proprietary LiDAR data and GPS acquisition

LiDAR data was acquired through the ERDF 156 project, that delivered point data at 1 point per square meter resolution and allowed for the generation of a low to medium triangulated image to enable 3D extrusion of the base map for easier visualisation. This was upgraded to a resolution of 40 points per square meter captured during the LiDAR scan of 2018 through the SIntegraM project. Terrestrial, handheld, backpack and Mobile laser scanners deliver considerable volumes of data.

Image-based capture

Imagery is acquired through manual photography and photogrammetry process. The former allows for directed image capture, whilst the use of drones aids directed data capture using uni-directional and gridded patterns. Through tools such as Metashape and Pix4D, the images are converted to georeferenced point clouds and in turn meshes (Figure 5) as well as DSM, DTM and orthoimagery as depicted in Figures 6a and 6b.

Figure 5: conversion process

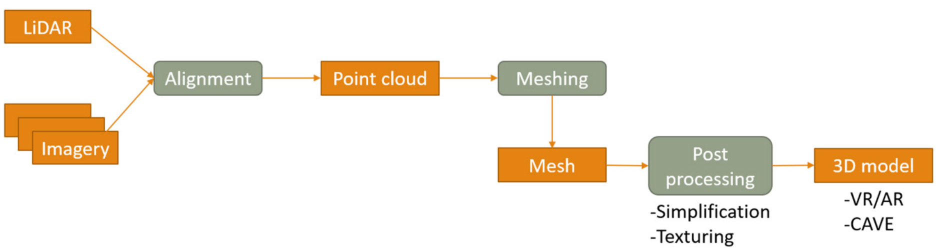
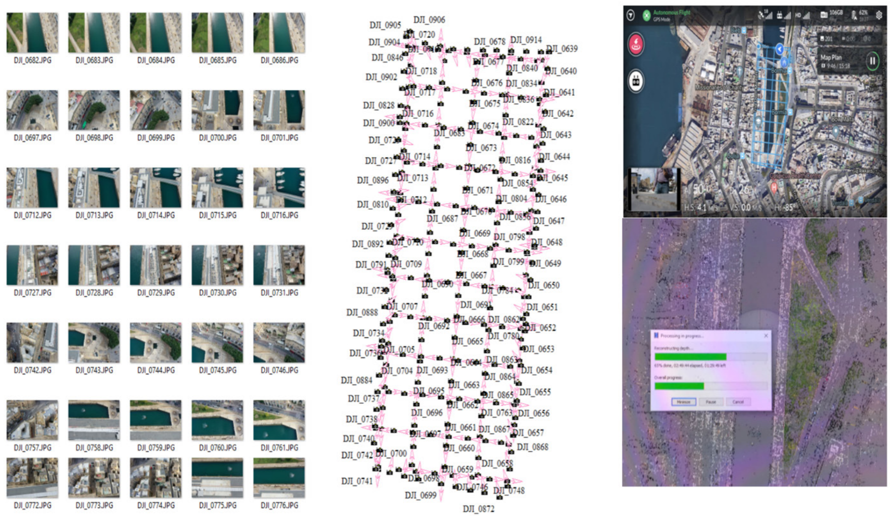
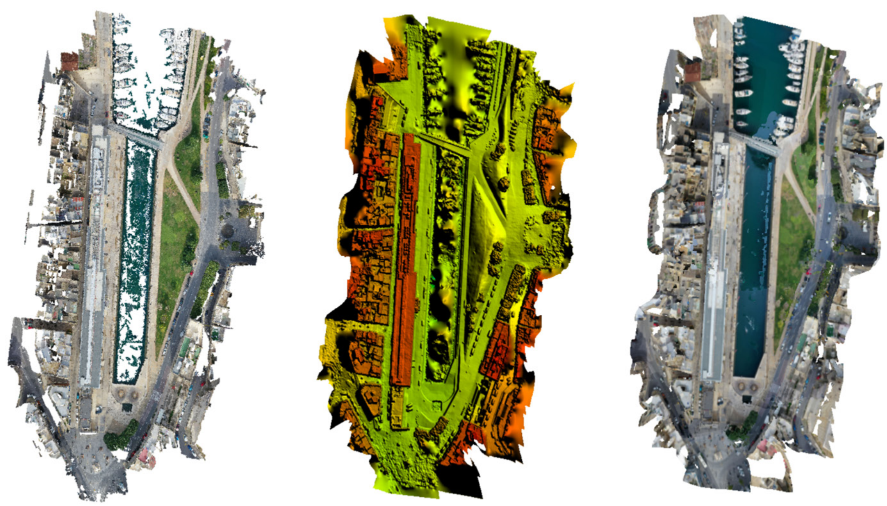


Figure 6a: Dock 1 process: Drone Capture, GIS locations, Grid mapping and pointcloud generation



Drone Capture | GIS locations | Grid mapping and pointcloud generation

Figure 6b: Dock 1 outputs: Pointcloud, DSM, Mesh



Pointcloud | DSM | Mesh

Video-based data capture

This process employed two main methods using drone technology and a hand-held video camera. Videos are converted to images which in turn employ the same method identified in the Image-based capture section.

Generation of crime scenes

In the first scene capture, the sites were generated using aerial-based technology where the 3D model was created through the implementation of LIDAR data Further data analysis enabled the integration of the aerial photos and the 3D data to deliver a virtual replication of the incident site. The video-to-image-to-pointcloud generation was based on a 4k image-based approach that allowed for the generation of a 3D interactive model that enables the user to rotate and view the model from different perspectives. This allows visual analysis of the crime scene, particularly as it offers the users a tool through which to one can revisit the crime scene digitally.

The process to investigate the area and identify potential incident dynamics required the generation of the area in 3D. The process entailed the following:

Phase A: Raw data and imagery acquisition

The data acquisition phase (Phase A) required a series of scene-related imagery and locational information which serves as the foundation for the generation of a 3D model (Phase B) and the later analysis in Phase C of the scene.

The process entailed the following steps:

- The acquisition of LiDAR data that included z-height (to determine the actual laser height of each point in the study area, sourced from ERDF156;
- The acquisition of aerial remote-acquisition imagery (to identify the coordinates and imagery of the points of interest), sourced from ERDF156;
- The acquisition of drone videos taken during the crime scene investigation process. Sources include the author, Malta Police Force Forensics Unit and other entities; and
- LiDAR scans acquired through the TLS, handheld laser scanners and aerial laser scanners, sourced directly in-situ.

Phase B: Data extraction

The data extraction exercise employed various technologies and processes that converted the diverse Phase A technologies into pointcloud information which would allow analysis of the scene in a 3D virtual environment.

- The different imagery and data were integrated into a spatial information system using diverse data conversion technologies inclusive of GIS, 2D and pseudo-3D systems; and
- 3D model of the area was generated for consumption in VR (virtual reality), AR (augmented reality), MR (mixed reality) and in-lab CAVE (Computer Automated Virtual Environment) present in the University of Malta MAKS Lab. Whilst MR restricts the user visualising the scene in a safe environment (as user cannot see beyond the screen), AR and MR enable the user to visualise the scene within the lab or the CAVE. Through MagicLeap the researcher was able to visualise crime scenes, port them out of the lab and allow visualisation of the scene in both enclosed (boardrooms, labs, courtrooms) and open environments (in-situ) allowing visualization of the scene superimposed on the actual urban or rural environment.

The 3D virtual environment was used to visit the scene from various angles and perspectives as well as to allow the court to identify potential scene dynamics. The resultant models are presented in various formats such as. laz and .ptx for pointcloud analysis and WebGL publishing, as well as meshes .dae, .fbx for VR, AR, MR and CAVE outputs (Figure 7).

Figure 7a: Incident scene pointcloud
Source: Caruana, 2019

Figure 7b: Simulated homicide mesh
Source: Grech, (2021)

Figure 7c: VR output

Figure 7d: Mixed Reality output

Figure 7e: CAVE output

Figure 7f: WebGL output

Phase C: Scene dynamics and analysis

Phase C in turn delivers on the calculations pertaining to the scene under study. The crime scene is depicted in terms of distance, areas, volumes, profiles and other measurements that would allow spatial forensic scientists and investigators to reach verifiable and valid decisions. The data is submitted in various formats to enable investigators using independent proprietary software and applications to carry out parallel studies and verify the outputs. Visuals are generated through WebGL and uploaded to dedicated sites for web-based viewing and analysis. LasPublish (potree) WebGL tool is used for this exercise as it exports coordinates, allows form measurements, 3D movement, profiles and exporting. Generated outputs such as DEM, DSM and DTM are delivered through Pix4D, Global Mapper and the TLS software RiScanPro, Cloud Compare and Lidar 360.

In Conclusion: Comprehending the Spaces

To comprehend the spaces involved in the crime scene, the purpose of this study was aimed at recreating the scene in 3D which would allow the court to be able to revisit the crime scene in an interactive 3D output and retain a crime scene before memory or the environment renders the site as vaporware, too deteriorated to analyse. The process to create and eventually to render the scene of crime is a laborious and intensive process requiring high-end computing power and tools that were necessary to allow investigators and the actors to acquire an accurate model of the scene of crime. The model, in conjunction with the GIS component allows the court to identify those areas that are depicted as potential areas serving as line of sight through scene rotation and immersion as well as a more detailed depiction of the scene of crime. The Maltese forensics activity into the spatial realm have been ongoing since 2013, which actions have improved the criminal forensics protocols and increased knowledge which in turn change the modus operandi in the Maltese Law Courts.

The next stages include further improvements in both methodologies, procedures, protocols and standard operating procedures in the diverse incident-related domains, inclusive of that based on upcoming technologies such as AI.

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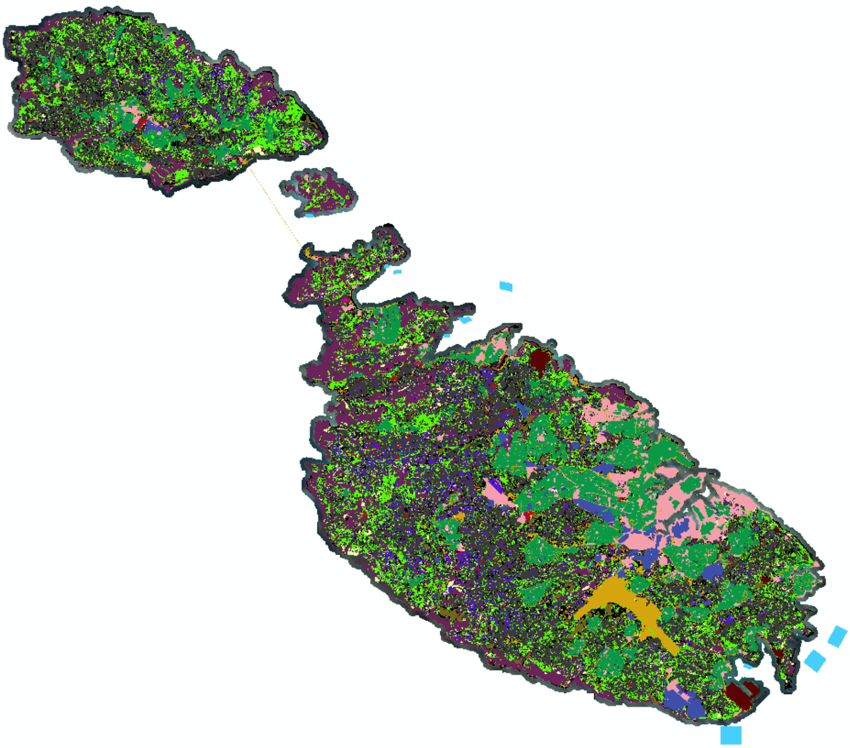
Pivot I

Cultural Heritage Domain



MT Land Use

CHAPTER 4

Exploring taskscapes in Neolithic Malta: Towards a territory-based approach

Annalise Agius

Keywords

Archaeology, GIS, Prehistory, Prehistoric Malta, Taskscapes, Neolithic Malta

Project Aim

The scope of this research is to explore the taskscapes and relationships between megalithic monuments, funerary sites, domestic sites and affordances of the surrounding landscapes in both Malta and Gozo, and to examine any patterns in the relationships between the location, site catchments and viewsheds for these two classes of sites.

Introduction to Maltese Prehistory in its wider context

The first clear evidence of human presence on the Maltese Islands dates back to the 6th Millennium BC, with a rapid change to the physical landscape (French et al. 2020). The Cambridge Gozo Survey, Dr Sara Boyle's Doctoral Research dissertation and the FRAGSUS (Fragility and Sustainability in restricted island environments) (French et al., 2020) indicate that during the Għar Dalam phase, eleven locations were occupied in Gozo, with five hotspots and three more densely occupied areas. The latter would then become the future temple areas of Ġgantija, Santa Verna and Ta' Kuljat (the eastern flank). Over the next phase, Grey and Red Skorba, occupation was more focused on the eastern flank of Ta' Kuljat, with settlement being maintained at Santa Verna with little evidence found for Ġgantija. Within the Skorba phase, nine locations were identified, five of which were hotspots, suggesting a more consolidated activity (French et al., 2020).

Landscape Studies

Landscape studies should go beyond the land. In island studies, the sea played an important role as a means of communication between islanders and people living in coastal areas (Horowitz and Fontes, 2018). In the Mediterranean there are very limited areas out of sight of land, as the nature of the Mediterranean coastline is hilly and mountainous (Horden and Purcell, 2000). In his GIS analysis of 2002, Grima, with the help of cost surface analysis, noted that 'embarkation points' close by, influenced the choice of location of the megalithic structures in Malta (Grima 2002).

Integration of Site Catchment Analysis with Visibility Studies

Within the Maltese context, a study by Caruana and Stroud (2020), and Lomsdalen (2021) analysed the visual links between the megalithic structures, their surrounding land and sea across the archipelago. These studies focused primarily on visual relationships between sites, landmarks on the horizon and the sea, and not their relationship with territory and its affordances.

The importance of GIS

The use of GIS in archaeology has in the past been criticised by landscape archaeologists who were concerned about the lived experience of landscape, such as Christopher Tilley. GIS sometimes tends to focus on environmental variables, leading to functionalism whereby space is dehumanised, relationships between cultural phenomena are conceived as mathematical and archaeologists tend to focus on process and behaviour rather than experiences and symbols.

Two types of data are required for Accumulation Cost Surfaces for a GIS approach namely, cultural and environmental. Cultural data were collected from archaeological investigations within the area of study, whereby investigations form a 'cultural landscape'.

Methodology

One of the main hypotheses that was critically examined and tested in this research is that the Neolithic inhabitants of Malta did not select sites at random. Instead, it is understood that sites are at an optimal location for their economic function. Vita-Finzi and Higgs (1970) state that sedentary societies are expected to be found in areas suitable for agriculture and mobile groups, in areas where grazing is favourable. This hypothesis of site relationships together with their landscapes and taskscapes, is scrutinised by making use of catchment analysis and viewsheds for different types of sites. Site Catchment Analysis can assist understanding the tangible relationship between different sites and their territories, whilst visual analysis leads to an understanding of the visual perception of and from sites within their territories. Territories are areas of spatial extent which mark an area of influence of a particular site.

Sites, Register, Research and Database build up

The main criteria for the selection of archaeological sites were the known sites pertaining to the Neolithic, those with a securely known location, those with an approximately known location, sites securely dated to the Early Neolithic, and those securely dated to the Late Neolithic. A database of all known Neolithic sites was created from the data acquired from the Superintendence of Cultural Heritage (SCH) in the form of a site code register (which also makes references to Temi Zammit Notebooks), research through the Museum Annual Reports (MARs), basic go to 'textbooks' in relation to the Prehistory of the Maltese Islands, Doctoral Dissertations concerning the prehistory of the Maltese Islands, the FRAGSUS study reports and the Planning Authority Local Plan Policies. The SCHs' (CHIMS) was also consulted.

A database on Microsoft Excel containing the available information on sites was created. Within this database, all known Neolithic sites were added, including those for which the information on date and location was less secure. Their respective coordinates were inputted within the Excel database so as to be imported into a GIS.

The use of GIS and data

Statistical analysis software RStudio was used for the Site Catchment Analysis of these archaeological sites and their respective isochrones. R studio is an open-source software for statistical analysis using the R programming language, which is a statistical language created to translate ideas to software easily and efficiently. Using R studio, the statistical probability that a pattern/difference occurred randomly was tested.

ArcGIS and QGIS use

The research used both ESRI ArcMap and QGIS as these programmes have different and complementary functions. On one hand, QGIS is much more user-friendly in certain tasks such as extracting point layers, georeferencing, and with a wider array of functions in relation to the viewshed analysis. On the other hand, ArcGIS, has a more 'professional' outlook and can offer more options to carry certain types of analysis such as improved map representations.

Site Catchment

Site Catchment Analysis is another method to define territories based on how humans engage and perceive their surrounding environment entails how human movement is facilitated or hindered by the topography of the surrounding landscape. To understand site catchments in this research, a package called 'movecost' was used to provide the functions for accumulated cost surfaces, least cost corridors in Rstudio (Alberti, 2020). The package movecost was required to be used in the data analysis as it creates and calculates accumulated cost surfaces and least cost paths between the different sites using a different number of cost functions, such as hiking function, time and/or energy expenditure amongst other variations. For these calculations and map creations, this package requires a Digital Terrain model, a starting location and destination location/s. During this study, the package was used both for singular and both for plural destinations.

Visibility Analysis

The visibility functions within QGIS allowed the possibility to input target heights apart from the observer heights. The observer height function is also available in ArcMap but the target height input is not. The observer height for view analysis was set to 1.48m (Malone et. Al, 2009), Parkinson (2019). When one takes into consideration the height of the observer, one must consider that the observer does not see from the top of his head, and a person sees at eye level, hence why the height of observer is modified to an eye level. The height of observer was calculated, by subtracting 0.12m from 1.60/1.607m.

A binary level viewshed was chosen, which option allowed the possibility to show areas with or without visibility, if one single observer point is chosen, or cumulative viewsheds if multiple observer points are created. The latter function was suitable for this study. The target height was set for 0m, 1m, 2.5m, 5m to understand visibilities of these respective target heights. This was done because although burial sites are underground or excavated in rock, in some sites such as the Xagħra Circle, there is evidence of megalithic remains lying over the site.

Targets at 1m and 2.5m were also set to allow one to understand intervisibility to the 'minor' megalithic sites which possibly where not as high as the larger megalithic complexes such as Ħaġar Qim, Imnajdra, Ġgantija and which may have been only partially visible. This might be a modern perception due to the few remains that are still present (Grima, 2008). However, the remaining megaliths or apses are of a smaller scale. A smaller scale construction possibly means a height of less than 5m. A 0m target was also used with the same rationale for that of structural sites, concerning the study of the landscape.

The cumulative viewsheds allowed information to be derived on how many locations/ points/cells that particular cell on the DTM was visible from. Viewshed analyses were executed for both structural and funerary sites to investigate the aspect of intervisibility between the sites.

Results and Discussion

Early Neolithic Period Structural Sites

From the evidence of sites gathered through Site Catchment Analysis for the structural sites of Taċ-Ċnus in Xewkija, Santa Verna in Xagħra and another site in Xagħra (as structural sites, within the 15-minute walking time isochrones for XAR 1905 and VRN 1905, there is evidence of burials, domestic sites, and scatters. For the Taċ-Ċnus, the evidence of such sites falls within a 60-minute walking time, with some of the features even being as close to as a 30-minute walking time.

In Malta, for both Borġ in-Nadur and Marfa, there are no Early Neolithic sites within a 60-minute walking distance, and this situation is replicated extending to a 150minute walking distance. There is only one site within a 15-minute walking time which pertains to the Early Neolithic period. These sites are both scattered and in very close vicinity (less than 15-minute walk time) to these structures, thus possibly structures forming part of the same site.

Early Neolithic Period Funerary Sites

The data for Neolithic funerary sites is even less in quantity with only 2 sites studied in Gozo, the Xagħra Circle and il-Mixta site. The Xagħra Circle falls completely within the pattern as those of the Early Neolithic structural sites, whilst the Mixta site is very much in isolation for the first 45 walking minutes. The first encountered site is the funerary sites of Kerċem and Xlendi, both pertaining to the Temple Period. The first same Early Neolithic site it encounters is Ta' Kuljat which showed intense traces of occupation during the Early Neolithic period. This site is the same approximate walking distance as the Taċ-Ċawla domestic site, and the Ta' Marżiena structure and scatter, at c. 75 walking minutes away. Another funerary site is also encountered (in Victoria Gozo).

For the funerary sites, within the Early Neolithic, three sites were studied: Skorba, Ta' Qali and Ta' Trapna. Whilst in Buqana, there are other sites pertaining to other 'periods' within the study within the 60-minute walking time, Ta' Trapna seems nearly in complete isolation apart from the scatter which is very close to the 60-minute walking time isochrone.

Temple Period Structural Sites

Within the Xagħra, Tas-Sruġ and the surrounding environs, there are several sites very close to each other, whereby, with a site catchment of a maximum of 60 walking minutes, one can find circa 33 sites including three domestic sites, six funerary sites and 12 structural sites amongst others. This indicates a heavy use of the area throughout the whole Neolithic period.

All structural sites in the Xagħra periphery are surrounded by domestic sites, funerary sites and structural sites in a considerable quantity within a 60-minute walking time.

Tad-Damma does not have any domestic sites nearby, the nearest known ones being just outside 60-minute walking time, if one takes into consideration the Early Neolithic sites of Santa Verna which is a confirmed domestic site in this period and considers Ta' Kuljat as a domestic site.

When one observes the results for the Structural sites in Malta, one can understand that a pattern is also present in Malta, slightly different that in Gozo, and sites are clustered. Clusters of structural sites are observed in the Ħal Farruġ Area, Ħal Tarxien Area, Mġarr, Kordin, Marsaxlokk and Mellieħa/Salini Area. Most structural sites are in clusters of two or three as can be observed from the Ta' Ħagrat/Skorba, Mnajdra/Ħaġar Qim, Tas-Silġ/ Tas-Silġ/Ħal Ġinwi, Kordin 1, 2 & 3, Ħal Tarxien/Ta' L-Erwieħ, Debdieba and Luqa/ Tumbata Area. There are very scanty domestic remains within Malta, and none have been securely dated to the Temple Period, and reference to the Skorba Site, Falka and Latmija site will be used as references to domestic sites. None the less frequency of other sites within a 15 and 60-minute site catchment can still be observed.

Observing the results for Site Catchment Analysis for structural sites in Malta, one can immediately note that there is a difference between inland sites and coastal sites. Inland sites appear to follow the pattern of having other types of sites within the immediate vicinity between 0 – 15 and 16 – 60 minute -walking time.

Temple Period: Funerary Sites

All sites follow the same pattern of having structural sites within the immediate vicinity of not more than 60-minutes walking time. The only exception is a site in Bużbeżija (Mosta), whereby no Temple period structures are present. The closest structural site is Skorba, which is just outside the 60-minute walking mark. Nonetheless for this site, the Falka Domestic Remains are within the 15-minute mark, and various other sites which are less securely dated and Neolithic sites, are within the confines of a 60 -minute walk.

Only one of Temple Period Funerary sites within the Xagħra area represent the same situation as that for the structural sites. These sites are the North Cave, tal-Qaċċa (a possible Temple Period site just outside the Xagħra Circle). The exceptions are Tad-Damma which has the same identical situation as that of the structural site since it is a few metres away, the rest of the sites in Gozo are not at a close distance to any other temple period sites however, when one takes into consideration the whole picture of sites, other types of sites are still found within the 60-minute walking time.

Soils

With structural Early Neolithic sites in Malta, within the 15-minute walking time, we see a prevalence in Terra soils and l-Inglin complex, Marfa, has Carbonate Raw Soils, whilst BRG 1922 has Xerorendzinas surrounding it. The situation changes within the 60-minute isochrones, with both sites having Carbonate Raw soils, Xerorendzinas, Terrasoils, L-Inglin Complex and the Irdum Sequence surrounding them.

The situation for funerary sites slightly different, with all sites surrounded by Xerorenzinas soil in the first 15 minutes of walking time, with variations to l-Inglin complex, terra soils and carbonate raw soils. Between the 1st and 2nd isochrone at the 60-minute walking mark, all sites have approximately the same soil types, this time with the tad-Dawl complex also being present, except for Skorba.

What is immediately evident for the Temple Period is that the surrounding soil families and complexes surrounding both funerary and structural sites are surrounded with Terra soils, Xerorendzinas and L-Inglin Complex soils. The rest of the complexes, although present, are less frequent. Considering that many of the sites of the Temple Period are found on Globigerina Limestone, the commonness of Xerorendzinas is to be expected, since that the parent rock of this layer is Globigerina Limestone.

Nearly half of the sites identified for this research pertain to the Temple Period whilst over half of the sites are attributed to a 'structural' type. Structural type sites are the sites where structures of a megalithic nature are found. Unfortunately, the other types of sites are somewhat of a more fragile nature than the megalithic structures, which are more likely to remain visible in the archaeological record. Cultivation, development, and urbanisation are the key causes of destruction of archaeological sites.

The locality of Xagħra appears to have been the hub of Neolithic activity in Gozo for both the Early Neolithic and the Late Neolithic as evidenced by the site catchment analysis carried out. The quantity of prehistoric sites of all types walking inwards from the outskirts of Xagħra is very little and it appears that one encounters mostly sites of a funerary nature. This site can be seen as one that possibly crosses a funerary landscape and once one reaches Xagħra a more diversified taskscape is found. However, having said this, funerary sites are not in isolation from the other types of sites, thus other taskscapes although possibly less obvious are still present. When one reaches Xagħra, the taskscape changes and becomes more of an agricultural task scape, as evidenced by the soils surrounding the sites. Nonetheless, this does not exclude that Xagħra had other functions as a funerary taskscape evidenced by the extension of the Xagħra Circle into the Neolithic and Tal-

Qaċċa site (possibly dating to the Temple Period) and a ritual taskscape considering that Ġgantija and other small scale structural sites are within these environs.

Through site catchment analysis and the different walking times, what was discovered is that sites in general are found within areas whereby the surrounding landscapes and environments vary greatly, in the minimum amount of time (Figure 1 and Figure 2). This was possibly to allow different raw materials to be obtained with minimal time and energy expenditure. All types of sites are in close vicinity to agriculturally viable soils. One can note the lack of sites in the central part of the island. Also refer to Figures 3 and 4 for isochrones output.

Figure 1: Concentration of Sites in relation to soils in the Maltese Islands

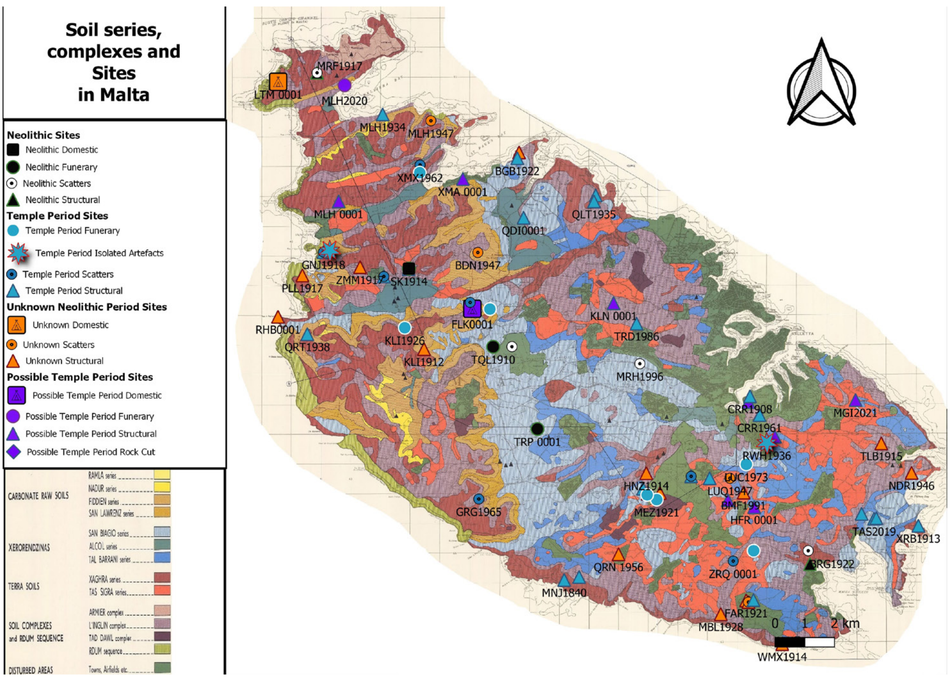


Figure 2: Concentration of Sites in relation to soils in Gozo

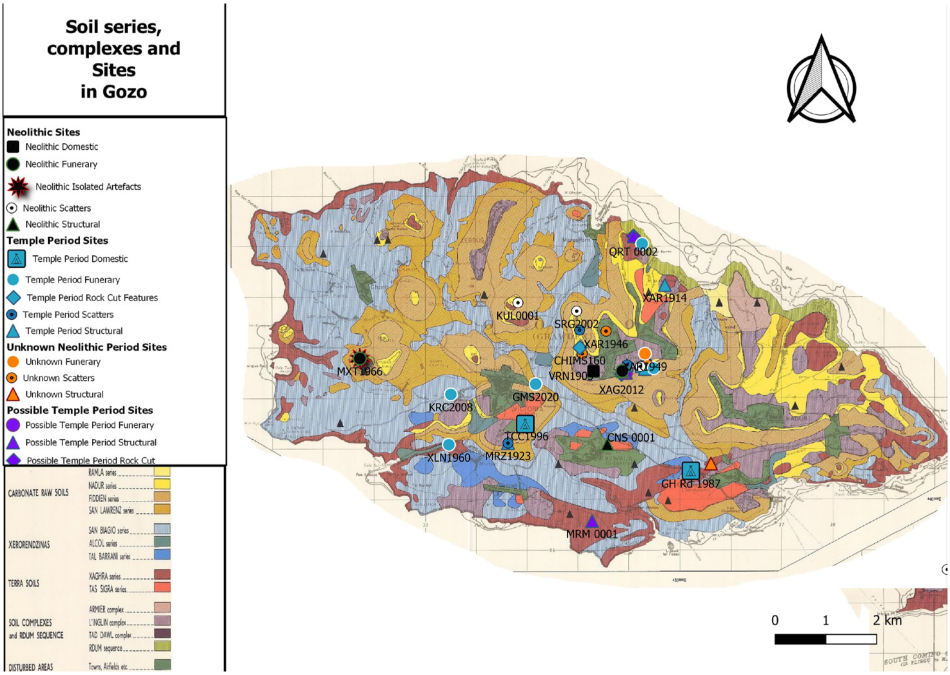


Figure 3: Isochrones (Generated from ACS), related sites, and geological formations for XMX 0001 - Xemxija 'Temple', San Pawl il-Baħar

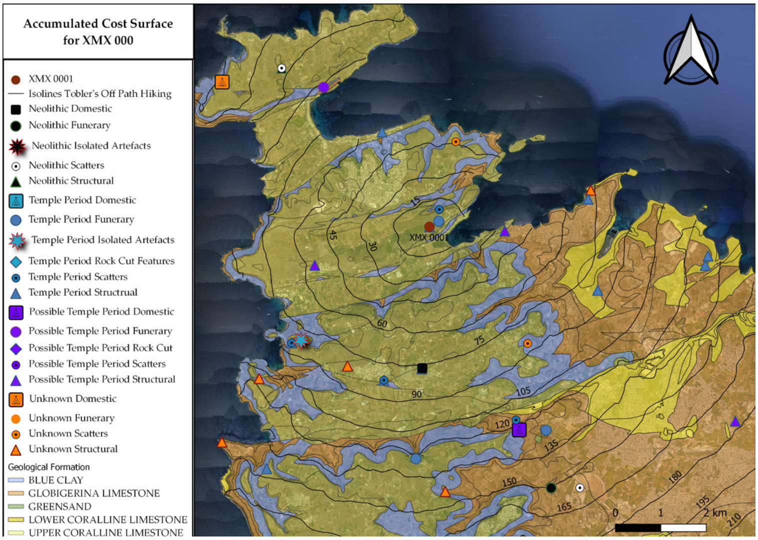
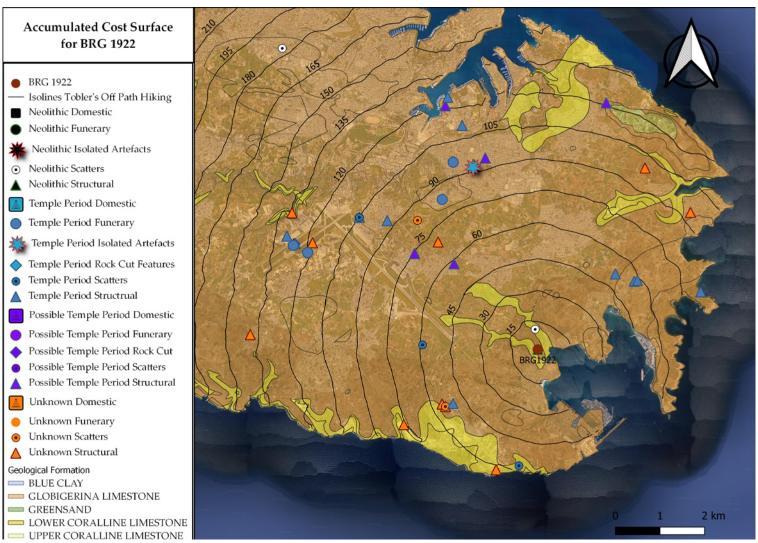


Figure 4: Accumulated cost surface isochrones related sites, and geological formations for BRG 1922, Borġ in-Nadur, Birżebbuġa



Funerary sites are not in isolation from the other types of sites with other less obvious taskscapes being present. In Xagħra, the taskscape changes, and becomes more of an agricultural task scape. This does not exclude the fact that Xagħra had other functions as a funerary taskscape evidenced by the extension of the Xagħra Circle into the Neolithic and a ritual taskscape considering that Ġgantija and other structural sites within these environs.

Through viewshed analysis, one could also note that structural sites have a positive visual relationship not just between these sites and also other types of sites, but there is also a positive visual relationship with the surrounding taskscapes and landscape. This implies that one can view the surrounding landscape from these structural sites, and, from the surrounding landscape one can in turn, view the structural site. The situation with funerary sites is slightly different. Although these sites are visible from structural sites and have a relationship with the surrounding sites in terms of proximity, visual reciprocity and visibility to other sites from funerary sites is not the norm especially in Malta (Figures 5 and 6).

Figure 5: Cumulative Viewshed from all sites under study, 0m target

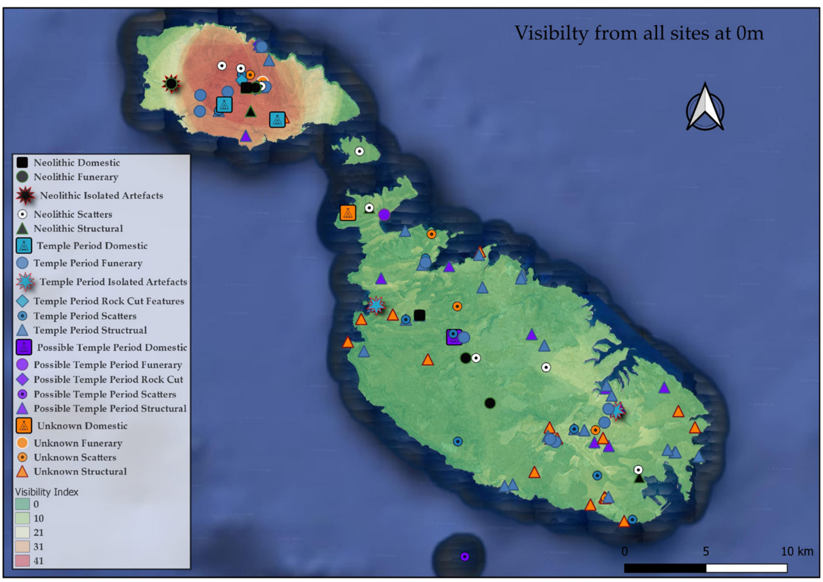
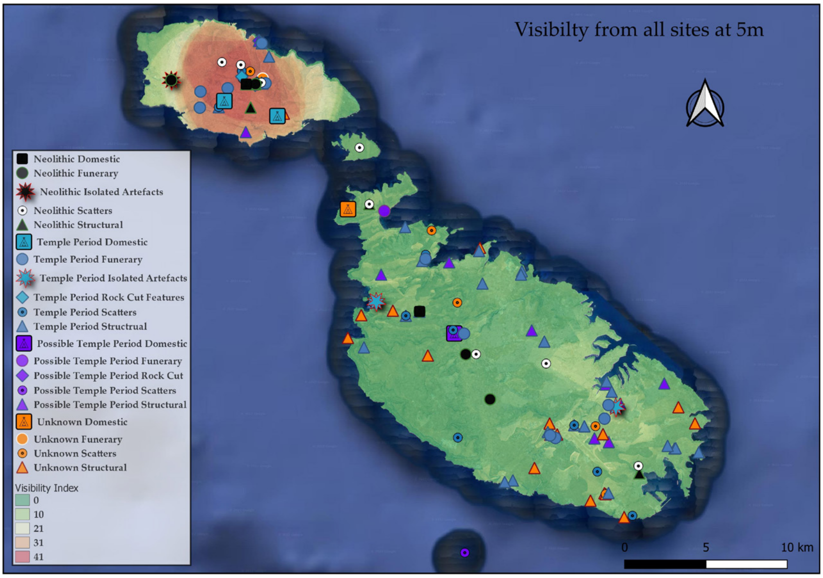


Figure 6: Cumulative Viewshed from all sites under study, 5m target



The situation in relation to the taskscapes, site catchments and their visual relationships in Malta and Gozo is very similar indicating that the locations of sites were not randomly chosen and there is a relationship between the different types of sites not only because they are in proximity on ground but there is also a positive visual analysis between structural sites and the surrounding landscape and sites. Nonetheless, as already stated there seems to be a negative relationship in Malta between funerary sites, their surrounding landscape, taskscape and sites. Taskscapes, as observed in Malta and Gozo throughout this study, are very overlapping as sites of different nature are present within the immediate vicinity of individual sites and therefore one can conclude that it is not the norm for the Neolithic period.

Recommendations

The study can incorporate further sites in the future, to include sites which are currently being discovered, and those whose date is not securely dated, yet however dating to the Neolithic as a broad term. If such a task is carried out, one would be able to confirm or otherwise the conclusions drawn by this study. This could help to further understand whether the sites pertain to a specific phase or period due to being closely associated to other sites with a securely dated period. This should also help to understand whether sites belonging to the same phase are clustered together.

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CHAPTER 5

Cultural Heritage sites risk management using GIS – a case study of the southern region of Malta

Claudette Debono Farrugia

Keywords

Cultural Heritage Sites, Risk Maps, GIS, Fuzzy Logic

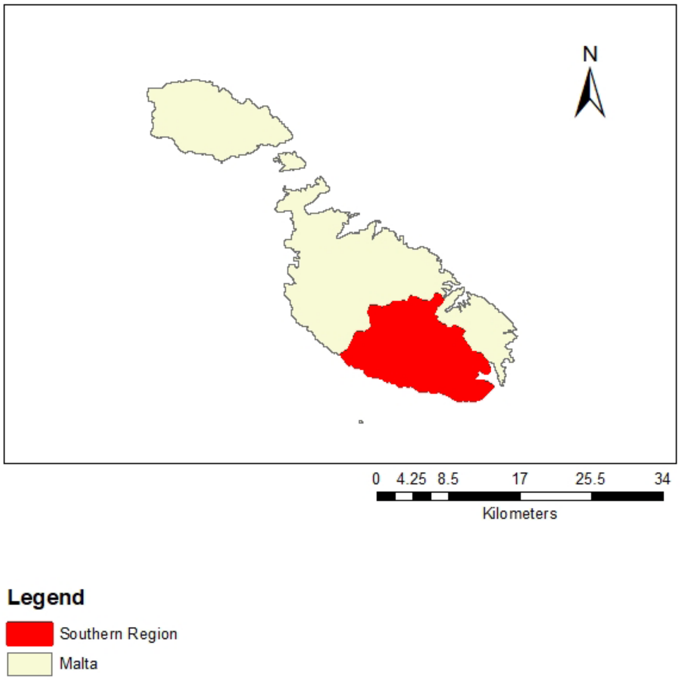
Project Aim

The aim of this project was to present a methodological framework to extract the natural, anthropogenic, and overall risk to cultural heritage sites and monuments located in the southern region of Malta.

Introduction

Malta is a small central Mediterranean archipelago whose location allowed the creation of peculiar characteristics from prehistoric times until recent times (Cassar, 2000). All these occupations have left their mark on the islands in the form of heritage buildings and monuments. Cultural heritage sites have great economic value, as the island depends on tourism for economic sustainability hence their maintenance and protection are imperative. The risk evaluation of this project was performed on the Southern region of Malta (Figure 1). This area has a specific spatial distribution of cultural heritage sites, which are found in several towns, villages and in rural areas, at low and high elevation, and, near and far from the coastline. These different geographical configurations provided different study parameters within the research framework and allowed for comparison through the analytical method applied. The southern region of Malta has an area of 78.9km^2 with a total of 529 cultural heritage sites (The Superintendence of Cultural Heritage, 2014).

Figure 1: The southern region of Malta



Risk can be seen as a measure of the combined likelihood of occurrence of a threatening event and of its potential consequences (Romão et al., 2016) while the term risk assessment consists of a formal and structured identification of the generic, specific risks and consequent calculation of the magnitude values associated with the different risks (Ramalhinho and Macedo, 2019). Based on these terms, risk assessment of cultural heritage sites can be defined as the identification of all potential hazards affecting them and the evaluation of the site vulnerability (Kioussi et al., 2013). Risk assessment methodologies are more effective when Geographical Information Systems (GIS) are used since digital, interactive maps and information systems offer more potential for information presentation, exploration and analysis (Dransch et al., 2010). GIS can be defined as a spatial analysis system for the organisation, storage, transformation, retrieval, analysis, and display of data where location is considered important. GIS was used to assess risk for cultural heritage in Paphos Cyprus (Agapiou et al., 2016). Another study on risk using GIS techniques was done around the archaeological area of Ancient Jeddah in Saudi Arabia (Elfadaly et al., 2020) and in Greece the risk potential with the use of GIS was studied for the Old Town of Xanthi (Giannopoulou et al., 2014).

Methodology

There are several framework methodologies that are aimed at developing a risk map of the deterioration processes affecting cultural heritage sites. However, they cannot be applied to every country since cultural heritage sites are often built from different materials and both the environment and landscape that they are situated in are also different. The value a particular society attributes to such sites may differ, and such value can affect the preservation of heritage sites in that while some societies value the importance of such sites and do their best to keep them well preserved, others just turn a blind eye to vandalism and neglect, some societies even use the destruction of sites to convey a political message. This study can be applied to all cultural heritage sites in the Maltese archipelago, after considering the natural and anthropogenic factors that may inflict a risk of deterioration on the fabric of cultural heritage sites.

Since Globigerina Limestone was historically and until a few years ago, a primary building material in Malta (Grøntoft and Cassar, 2020) any attempt at assessing risk to cultural heritage sites in Malta needs to start from an overview of risk associated with exposure of Globigerina Limestone. In this project both natural and anthropogenic risks were examined. With regards to natural hazards, slow ground movement (Blue Clay Layer Presence and Presence of Faults), salinity (Proximity to Coastline and Elevation and Aspect) are the most common possible risks with the highest availability of processing data (Debono Farrugia, 2021). With respect to anthropogenic risks, pollution (Proximity to Roads) and urbanisation have been analysed. The data used in this study is secondary, public data sourced that was sourced online (Debono Farrugia, 2021).

Ground Motion Risk

The geological setting of Malta often shows the overlapping of stiff and bristle limestone plates on thick Blue Clay layers which lead to geomorphological processes such as slides or slow flow phenomena in the underlying ductile units and brittle ruptures involving the overlying rock masses which lead to ground movement that affects cultural heritage sites (Gigli et al., 2012). Malta is also crossed by two main fault systems representing the effects of two separate rifting episodes in the vicinity of the islands, namely the Great Fault and the Magħlaq Fault systems. Near-fault ground movement tends to increase the displacement response in buildings (Baker, 2007). Ground motion data was sourced from the Continental Shelf Department website (Oil Exploration Directorate, 1993). Blue Clay Layer Presence: The digitised Blue Clay layer was selected from the tertiary layer and reprojected to WGS84 UTM 33N. Euclidean Distance was applied with a maximum distance of 500m, and the image was then reclassified with 10 classes of 50m each and saved as 'Blue Clay risk layer'.

Faults Presence: The digitised faults layer was reprojected to WGS84 UTM 33N and all faults were kept for analysis. Euclidean distance was applied also with a maximum of 500m, and the image was then reclassified with 10 classes of 50m each and saved as Faults risk layer.

Sea Erosion Risk

Salinisation is a slow-onset threat, particularly for monuments located close to the coastline. Sea Erosion risk was analysed by including both the distance to the coastline with respect to elevation and the derived aspect related to the dominant recorded wind direction (NW) (Ravankhah et al., 2019).

Proximity to Coastline: This digitised risk layer was extracted from the Malta boundary data by geocoding a new geodatabase of the coastline in the vicinity of the study area. Euclidean distance was applied with a maximum distance of 5000 meters and the image was then reclassified into 10 classes of 500 meters each. The raster was then clipped by mask to the Malta shapefile to avoid any values outside the islands' area being calculated in the analysis.

Elevation: A Digital Elevation Model (DEM) acquired from the Copernicus Land Monitoring Service was reclassified according to elevation levels with 10 classes of 5 meters each up to 250m.

Aspect: The layer was extracted from the DEM and was reclassified with values 292.5 to 337.5 (values for Northwest aspect). Euclidean distance was then taken from the Northwest aspect which was then reclassified in 10 classes of 50 meters each up to 500 meters.

Pollution Risk

Air pollution is known to have an accelerating effect on the weathering of fresh limestone surfaces. In the long term, air pollution will work together with other deterioration processes, and its effects will have repercussions on the overall behaviour of the limestone surface and building in a polluted environment (Grøntoft and Cassar, 2020). The main weathering processes are due to a combined action of rainwater and atmospheric pollutants (particularly the carbonaceous particles due to combustion) deposited on the surface of the monument (Camuffo, 1986). To extract air pollution risk, a shapefile of the road network was downloaded from Open Street Maps (OSM) and reprojected to WGS UTM 33N. The primary and secondary roads were selected, Euclidean Distance was applied and the dataset reclassified into 10 classes of 50 meters each up to 500 meters.

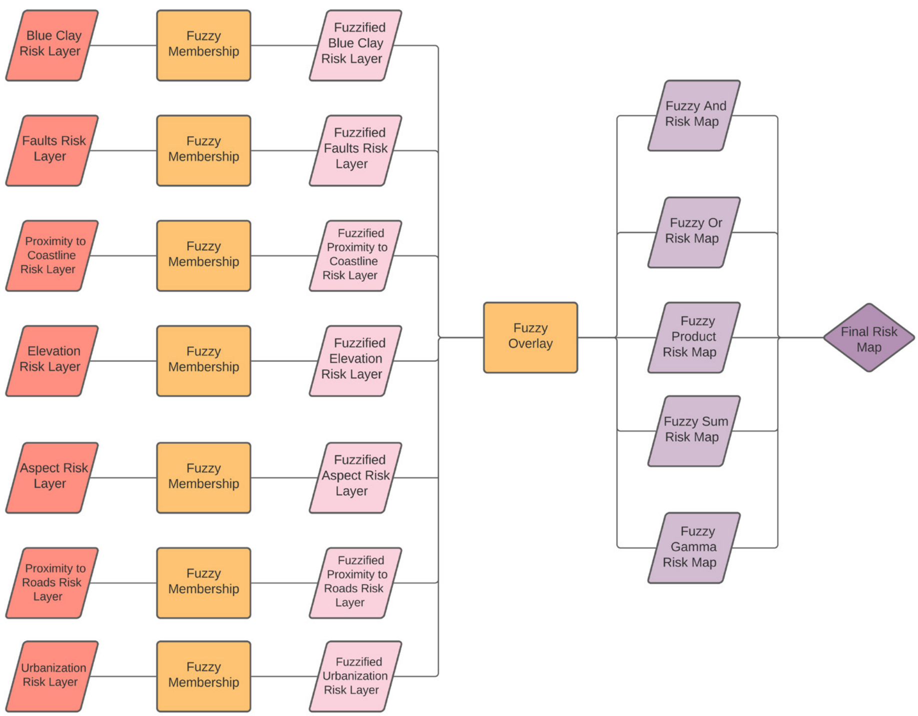
Urbanisation Risk

Urbanisation constitutes a mounting threat to cultural heritage sites. At risk are not only cultural heritage sites but also traditional architecture (al-Houdalieh and Sauders, 2009). Urbanisation risk was calculated by proximity to urban centres. An Open Street Map database was used by selecting the residential, commercial, industrial and quarry areas. Euclidean distance was then calculated from the vicinity to urban areas and reclassified into 10 classes of 50 meters each up to 500 meters.

Risk Map Development

In GIS, Fuzzy Logic is applied through a two-step process (Figure 2). In the first step the Fuzzy Membership tool was used to transform the 'risks' datasets to the 0 to 1 probability scale instead of the 0 and 1 Boolean logic. Fuzzification converts the original values of phenomenon to the possibility that they belong to a defined set. Fuzzy sets, therefore, provide the ability to mathematically describe concepts of vagueness and the degree of membership reflects the rate to which the element belongs to the set.

Figure 2: Fuzzification process and application of fuzzy overlay analysis



Membership functions play a vital role in the overall performance of fuzzy representation as they are the building blocks of fuzzy set theory, that is, fuzziness in a fuzzy set is determined by its membership function. Therefore, the shapes of membership functions are important for a particular problem since they effect on a fuzzy inference system. When choosing the appropriate membership function any shape and form can be used as long as it maps the given data with desirable degree of membership.

To determine the overall risk, the Fuzzy Overlay tool was used in ArcMap 10.6 to combine the risk possibility layers into a single layer representing membership in the output set. This tool uses Fuzzy logic that allows better reflecting the natural estimated properties and modelling of uncertainty of spatial data (Ďuračiová et al., 2013). The overlay methods of the tool allow the analysis of the possibility of a phenomenon belonging to multiple sets in a multicriteria overlay analysis based on set theory analysis (ESRI, 2018). To apply fuzzy overlay in ArcGIS all fuzzified risk layers were overlaid using the fuzzy overlay tool in the Spatial Analyst tool. Since no similar studies, with the use of fuzzy overlay analysis to investigate risk to cultural heritage sites, were found in the literature, as most use weighted overlay analysis or AHP, all fuzzy overlay methods were used and A total of five risk maps were created. The most relevant risk map was validated against a sample of the sites taken from the cultural heritage sites dataset.

Research Validation Methodology

To understand the model behaviour and its limitations, a sensitivity analysis was carried out. Since natural factors affecting the conservation of cultural heritage sites do not change, sensitivity analysis was carried out on the anthropogenic factors of the model. According to the NSO the percentage increase in Malta's population from 2010 till 2020 was of 6.58% (NSO, 2020). A sensitivity analysis based on increasing risks based on anthropogenic pollution by the same percentage increase. A sensitivity analysis was carried out on the final risk map using the Gamma function of the Fuzzy overlay analysis by increasing the Euclidean distance of the anthropogenic risk factors that is the pollution/road distance risk by 6.58% in to 10 classes by 53 meters up to 530 meters.

Discussion and Results

From the overall fuzzy overlay analysis, it resulted that the sites that are most at risk are in the Girgenti and Fawwara parts of the study area. Both areas are found on a promontory in the western part of the study area. With regards to ground movement risk, presence of a Blue Clay layer and presence of faults are in this area (Oil Exploration Directorate, 1993). The area is close to the coastline but is located at a high elevation and is exposed to northwest winds. The area is found in a rural part of the southern region away from urban centres and with only one major road present. However, in the area there are two large quarries that were included in the urbanization risk layer given that quarries emit a major source of air pollution in the form of dust emissions. Air Pollution is also present due to heavy vehicle emissions. Vibrations, from quarries due to blasting operations, are also another factor that may impact the preservation of cultural heritage sites.

To analyse the best fuzzy overlay method a comparison of all risk maps was done, and the average raster value was calculated. From the results it is evident that the overlay method that best represents the results is the Fuzzy Gamma method (Figures 3 and 4). The Gamma overlay method visually allows the relevant authorities to prioritise cultural heritage sites in order of the risk attributed to them in that while the other overlay methods result in maps with a high raster value of 1 to all the sites at risk, the Gamma fuzzy overlay method attributed raster values that highlight the sites most at risk which is a very important factor in choosing a risk map since risk maps are used to aid in the explanation of the extent of risk to non-technical persons who may on the other hand easily understand in a picture with the appropriate colours.

Figure 3: Fuzzy Overlay Analysis results

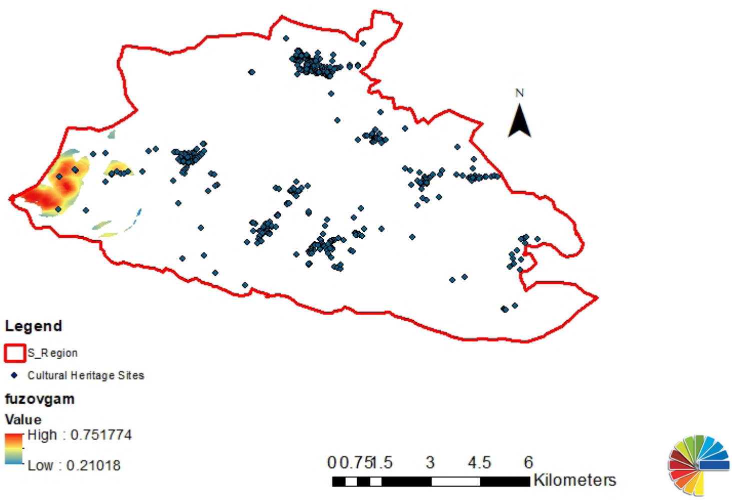
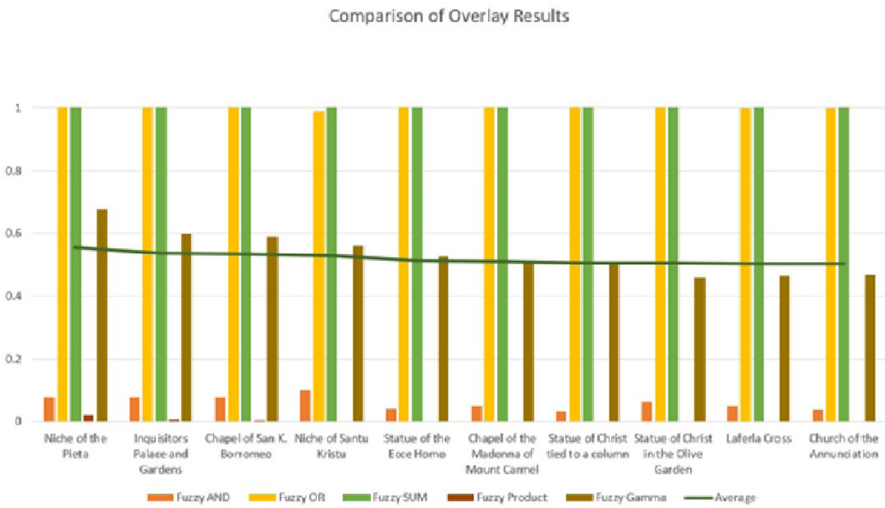


Figure 4: A comparison of the overlay results and average



An onsite visit was carried out at the sites that were most at risk, to corroborate the results of the study. For this purpose, evaluation sheets were prepared with the name of the site, an image, history and general description of the site, the current state and a checklist of the risks identified in the methodological framework and if they are evident on the site. It resulted in the evaluation of the Chapel of the Madonna of Mt. Carmel, the Church of the Annunciation, and the Laferla Cross, which are all found in the Girgenti and Fawwara areas and had signs of deterioration due to ground movement. With regards to the other risks identified in this study, the sites are not in a highly urbanised area, but they are in close vicinity of quarries with the niche of the Pieta being most affected. With respect to the risk of erosion due to sea salt aerosols, even if the sites most at risk are situated at a high elevation, they are not positioned far from the coastline and evidence of sea erosion is present in the form of alveolar deterioration. With respect to air pollution, the sites most at risk are not found in the vicinity of major roads and this is evident from the lack of black crust present on the identified sites.

Recommendations

As a result of this study some recommendations are being put forward to local heritage authorities responsible for the protection, restoration, and preservation of cultural heritage sites.

The first recommendation is to establish a single database on cultural heritage sites in Malta where every authority can contribute the data it creates. This recommendation is being put forward since the only dataset which is available online on cultural heritage sites is the National Inventory by the Superintendence of Cultural Heritage and even this data needs to be updated and made available to download as a spatial dataset. No information is available online on when and if the cultural heritage sites were restored or not. Having a detailed open-source dataset would enable the pursuit of studies on this subject, something which the Maltese Cultural Heritage sector can benefit from.

2. This study encourages a greater use of fuzzy logic overlay as a viable and often overlooked, analysis type especially in risk studies concerning cultural heritage sites. Fuzzy logic reduces uncertainty and eliminates the need of expert knowledge needed to establish weights in overlay weighted analysis and offers the freedom to choose the fuzzy membership type according to what the researcher deems fit. Also, with tools such as ArcGIS, intensive mathematical processing that fuzzy logic entails is made easier for heritage managers to apply through the spatial analysis tool resulting in maps that can be clearly understood by everyone which make them important tools in conveying the message of risk to cultural heritage sites.

3. With the benefit of hindsight, there are a few aspects which this study would have benefitted from if applied. One aspect was the use of remotely sensed data to update the basemap whenever new datasets are available. Remotely sensed data, for example, can be used for pollution monitoring and having it incorporated in this study would enable cultural heritage managers to set up mitigation techniques to protect cultural heritage sites. InSAR Ground Movement Monitoring datasets can also be used to enhance this study and recently Copernicus started providing reliable datasets regarding natural and anthropogenic ground motion over the Copernicus Participating states with millimetre accuracy (Copernicus, 2022).

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CHAPTER 6

Osteological analysis of human remains

Debra Jane Camilleri

Keywords
GIS, Bioarchaeology, Human Bone, Taphonomy, Ancestry Determination

Project Aim

The aim of this study was to (1) to perform a demographic analysis of the commingled human remains (sex, age and ancestry); (2) to assess pathologies and document trauma versus taphonomic processes on the bone elements utilizing a GIS-based approach; and (3) to show that osteological analysis, in conjunction with the use of GIS, could provide insight into the origins of these human remains found in the hidden passageways of San Girgor.

Introduction

In 1969, a very large assemblage of commingled skeletal human remains was found in hidden passageways in the rooftop of the old parish of St. Catherine's in Żejtun, Malta, now known as the Chapel of San Girgor (St. Gregory's). The first mention of this chapel was made by Bishop de Mello in the Rollo (inventory) of 1436, which provides evidence that this parish had already been well established (Ciappara, 2008) by the early 15th century, and cemeteries most likely would have existed nearby. The discovery of the remains cultivated various beliefs regarding their origins, which circulated for decades. The analysis of the remains, ten years after their initial discovery, left many questions unanswered. The need to understand who these individuals may be, their cause of death and how the human remains came to rest in the hidden rooftop passageways of a 700-year-old church provided a significant purpose for this present study.

The Chapel of San Girgor is in the south-eastern region of the Island of Malta in an area of Żejtun which was once considered to be a major trading centre and residential area for merchants (Figure 1). The sheltered harbours around this area were very strategic and attractive to corsairs and enemies who regularly attacked Malta (Fiorini, 2014). As one of the highest points in Malta, at 60 metres above sea level, Żejtun and San Girgor for that matter, provided excellent vantage points for two significant harbours and ports, including St. Thomas Bay in the northwest, Marsaxlokk in the southeast and Marsascala Bay in between, to the east.

The design of the chapel used the advantage of its elevated physical position, and most would agree that its purpose extended to the defence of the region (Buhagiar, 1979; Fiorini, 2014) with lookout windows strategically positioned in the south and east walls (Figure 2). These particularly useful lookout windows (Figure 3) are within the 'hidden' passageways and it would be reasonable to assume that, until this lookout was deemed no longer necessary, accessible passageways would have been crucial, at least until after the last attack in 1614, allowing those on watch to move about, certainly not with human remains scattered throughout. This would suggest that the remains were placed in these passageways after 1614, although the individuals may have been from earlier or later time periods.

Figure 1: Location of Żejtun, Malta circled in red

Source: PA Geoserver 2022

Figure 2: Close-up of Chapel from above as it is exists today. Arrows show the location of three passageways; (a) Passageway 1; (b) Passageway 2; (c) Passageway 3

Source: PA Geoserver 2022

Figure 3: Hidden Passageway 1 with lookout windows

Source: Photograph, October 2020

Since the discovery of the human remains at San Girgor in 1969, (Figures 4 and 5), Bonnici (2019) notes that there were varying theories regarding their origins. These included the belief that the remains belonged to those who were hiding from and subsequently killed by the Turks in the Ottoman attack of 1614, or that they were left behind and starved to death following the attack. Others thought the remains might have come from burials around the chapel area, removed when the chapel was being enlarged in the late 16th century; or possibly from burials being cleared near the chapel to make space for newly deceased individuals.

Figure 4: Framed pictures of the discovery from 12th March 1969 showing the sacristan next to the human remains found in Passageway 2 and 3

Source: Courtesy of Wirt Iż-Żejtun. Imagery captured in April 1969

Figure 5: Human remains inventoried and logged from the passageways at the Chapel of San Girgor, stacked on wooden shelving units and placed in Passageway 3

Source: Imagery captured in October 2020

In 1979, ten years after the discovery, the human remains of this commingled assemblage were the subject of a palaeopathological and anthropological analysis by Ramaswamy and Pace (1979, 1980). Their report provided a demographic analysis of the remains including a determination of their sex, age, and pathologies, with the aim of ascertaining whether evidence existed to show prior burial under soil (Ramaswamy & Pace, 1980). They concluded that the remains were most likely buried elsewhere initially, and that the passageways could have been used as an ossuary (Ramaswamy & Pace, 1980). Unfortunately, the raw data and bone inventory on which Ramaswamy and Pace's (1979, 1980) reports were based were no longer available. In addition, limited archival research was performed and no scientific dating had been done (although they had recommended this) to provide specific information about the period to which these human remains belonged, creating information gaps in their research reports. The Superintendence of Cultural Heritage (SCH), in collaboration with Wirt iż-Żejtun and Heritage Malta, recognized the importance and the need for additional scientific analysis and research that could shed further light on this assemblage (Grima et al, 2018 Heritage Malta & Wirt iż-Żejtun, Unpublished internal report), and this was the springboard for the present study.

Methodology

The use of standardised methods and practises in osteological analysis, some of which were not pursued decades ago or did not exist, in the context of recently obtained radiocarbon dating results, set the foundation to sort through the assemblage, one bone at a time, to obtain further insight. In addition, a GIS-based approach which has been utilised successfully by zooarchaeologists (Marean et al., 2001; Abe et al., 2002; Stavrova et al., 2019) on faunal remains, was applied in this study, to 143 (74 left and 69 right sided) human femurs. Due to the large amount of data, the aim was to obtain a visual representation of spatial patterns and density of taphonomic indicators, including antemortem and perimortem evidence versus any postmortem alterations, to rule out interpersonal violence and confirm external disturbance. Intensive archival research and recent radiocarbon dating results were used to provide the historical context.

A full inventory of the human remains provided the foundation for the demographic analysis and biological profiles after determining the minimum number of elements (MNE), minimum number of individuals (MNI), sex, age, and ancestry of this population.

Antemortem, perimortem and postmortem trauma, pathologies and taphonomic damage were analysed to determine the potential cause of death. Perimortem evidence such as trauma resulting from violence would have indicated the individuals had died at the site making this a primary burial. Antemortem trauma (for example healed fractures) or postmortem evidence (damage from use of tools, such as by those of an undertaker, after death) on the other hand would have indicated the individuals had been moved from a primary burial, such as a cemetery.

Non-metric and metric approaches (Buikstra & Ubelaker, 1994; Bass, 2005; Burns, 2013; Klales, 2018; White, 2012; Alqahtani et al., 2014) were used to determine the MNE, MNI, sex, age, and ancestry. Each complete element was counted as one element to determine the MNE, which provided a total of 1858; and the most represented bone element was the left humerus which established an MNI of 92. The skeletal material was in good condition but did show evidence of postmortem damage primarily exhibited on the long bones, and for this reason, the femur was selected as the most suitable element for the GIS-based approach.

The ox coxae (pelvic bone) is considered the most reliable element for sexing and ageing (Buikstra & Ubelaker, 1994; Spradley & Jantz, 2011; Bass, 2012) and non-metric analysis was performed using various morphological traits, following the Phenice (1969) method for sexing, and the Suchey-Brooks method (Brooks & Suchey, 1990) and Lovejoy et al. (1985) for ageing. Stages of epiphyseal fusion (Webb & Suchey, 1985) in the postcranial skeletal material and fusion of sutures in the crania (Meindl & Lovejoy, 1985), which vary based on age, were used to corroborate the statistics derived from the above analysis. Various landmarks on the cranium also provide reliable sex and age determination and following Buikstra and Ubelaker (1994), Walker (2008), White (2012), and Klales (2018). In addition, the dentition present in the maxillae and in the mandibles was assessed to corroborate age, following Alqahtani et al. (2010, 2014).

Although the author acknowledges that DNA analysis would have provided more conclusive evidence of ancestry and geographic origin, in the absence of the opportunity to perform such testing, metric and non-metric analysis was performed on the crania to determine ancestry and understand the origin of this population. The fact that the commingled assemblage was found in passageways of an early mediaeval Catholic church, located in what was once a remote and rural village on a small island in the Mediterranean, led this author to expect the remains to belong to locals, most likely of European ancestry. On visual inspection using characteristic traits following White et al. (2012) and acknowledging that variations do exist within as well as amongst populations, it was evident that five of the 35 crania that could be analysed exhibited evidence of non-European ancestry. This provided further motivation to assess ancestry. It was crucial to select a method which included a reference population representative of the assemblage being studied, to ensure a high degree of accuracy. The Giles and Elliot (1962, 1963) method using cranial measurements, discriminant function analysis and information forms devised by Gill (1984) was based on the Robert J. Terry Anatomical Skeletal Collection held at the Smithsonian Institute and the Hamann-Todd Osteological Collection housed at the Cleveland Museum of Natural History. These collections include a heterogeneous population, both urban and rural, European, and African males and females from the 19th century, who fall into older adult categories.

Evidence logged included that which took place (1) prior to death (antemortem trauma) such as healed fractures; (2) at death (perimortem evidence) such as interpersonal violence including cut marks from weapons or unhealed fractures; (3) following death (postmortem effects) such as animal gnawing, environmental weathering, and tool/cut marks from undertakers' tools. For the latter, Baustian (2014) notes that these could be intentional, natural, or accidental. The remains were analysed following Behrensmeyer's (1978) six stages of weathering and Sorg's (2019) work on trauma.

Various studies stemming from zooarchaeology (Marean et al., 2001; Abe et al., 2002; Stavrova et al., 2019) using a GIS-based approach on faunal remains, and more recently applied by a few researchers to human remains from archaeological contexts Hermann (2002), Hermann and Devlin (2008), Ciesielski and Bohbot (2015) and Parkinson (2018) have used this innovative method to understand commingled remains. Features on maps (represented as points, lines, and polygons) are instead features of and on human bone (the elements themselves, cut marks, fractures, and modifications) where the bone becomes the 'geographic landscape' and the base map.

Abe (2002) argued that GIS has several strengths that other methods cannot offer in the analyses of bone when faced with the challenges of large assemblages and stated that zooarchaeologists have been "attempting to describe bone fragments and their surface modifications as numbers on a database, when in reality the problem has always been one of image" (p. 661). Unfortunately, the adoption of GIS methods in bioarchaeology appeared more than 10 years after zooarchaeologists were experimenting with the approach, and although the technology has advanced, few have embraced the method for the study of human commingled remains.

In this study, photos of a complete right and left femur were taken and converted into TIFF/PGN files which were used as the base maps for the tool/cut mark features. After digitising the right and left femur, ArcGIS 10.6.1 was used to create a polygon shape file for each view (anterior, posterior, lateral and medial) of both the right and left femur (Figure 6). All views were placed in the same layer respectively for the right and left side of the femur. Three sections (proximal, midshaft, distal) were created on each polygon of each view of the femur by splitting the polygon shapefile. A polyline shapefile (Figure 7) was created on which tool/cut marks were drawn at the respective locations of the femur to populate the attribute table. Finally, the Kernel Density tool was utilised to create heat maps for each view which visually displayed 'hotspots' for the marks.

Figure 6: Images of left and right femurs and corresponding polygons of four views with proximal, mid-shaft and distal sections presented in separate polygons

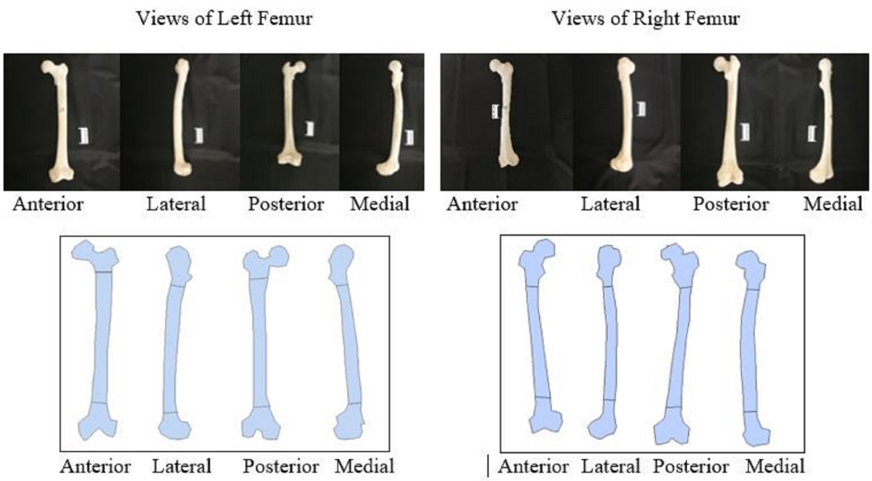
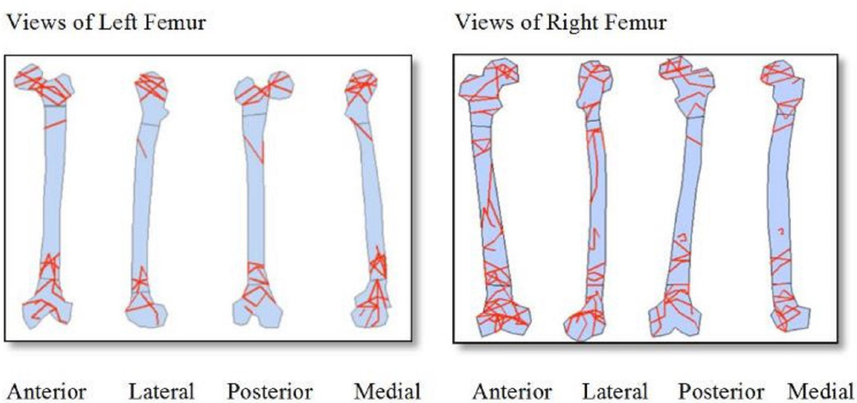


Figure 7: Polylines representing tool/cut marks on left and right femurs



Each tool/cut mark was labelled based on the side of the femur, the view, and the location on the femur. For example, a tool/cut mark on the anterior side of the distal end of a right femur would be logged under RAD. This collected data was compiled in an attribute table for use with GIS software (ArcGIS, 2022) and the different abbreviations used during this exercise are listed below in Table 1.

Table 1: Abbreviations used to log tool/cut marks on femurs

RAPr	RAM	RAD	LAPr	LAM	LAD
RLaPr	RLaM	RLaD	LLaPr	LLaM	LLaD
RMePr	RMeM	RMeD	LMePr	LMeM	LMeD
RPPr	RPM	RPD	LPPr	LPM	LPD

The statistical data showed little antemortem or perimortem trauma, and the objective was then to highlight the significant taphonomic processes and show the spatial patterns of these processes. The value selected for the population field was 'None', as each feature (polyline) was to be counted once, and the geographic coordinate system utilised was 'Web Mercator'. A magnitude-per unit area from the polyline features was calculated using the kernel function which determines the density of features in a neighbourhood around those features (ArcGIS, 2022). This showed the concentration in any given area.

Discussion and Results

The analysis demonstrated that the 1858 commingled remains consisted of at least 92 individuals, primarily older adults, both male and female. Although most of were of European ancestry, 7% were of sub-Saharan ancestry and were most likely domestic slaves based on archival research (Żejtun Parish Archives 1580-1606 & 1606-1766). Statistical analysis showed that 63% were females and 37 % were males, with the majority falling in the older adult category (age 50+). Only 4% in the assemblage were under the age of 15, with no very young children represented, as the youngest found was approximately eight years old.

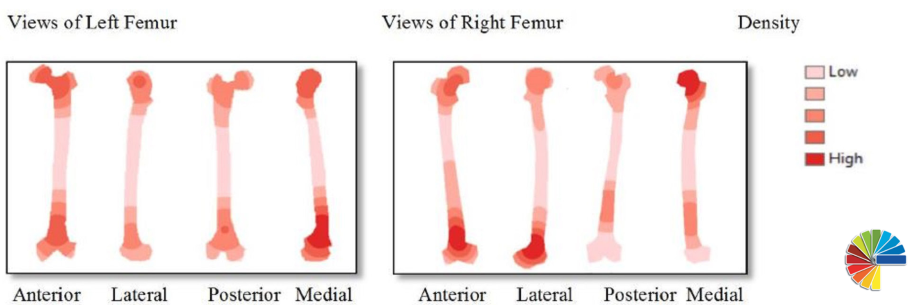
The report on radiocarbon dates (Molnár, 2020) indicated the material originated from as early as AD 1440 to 1660 providing evidence that the individuals are from different periods which was cross-referenced and corroborated by archival research.

While assessing the postmortem tool/cut marks it is worth noting that out of the 143 femurs (53% left and 47% right), 32% had soft tissue; 9% had healed fractures with 58%

of fractures located on the midshaft; none of the tool/cut marks appeared to be due to interpersonal violence and were instead due to postmortem damage. The location and consistency of the damage also shows a non-random pattern.

'Hotspots' (dark red shading) are evident on the heat maps which represent the highest density of tool/cut marks in each section on each view (Figure 8). Areas where very few or no tool/cut marks existed are represented by the light pink shading. The distal ends of both femurs in all views seem to have the highest density, with the highest located on the anterior side of both the left and right femurs as well as medial sides. This could be an indication of an undertaker's tool used to rake the skeletal material from left to right (affecting the distal ends of left femur and medial of the right) or right to left (affecting the distal ends of the right femur and medial ends of the left).

Figure 8. Heat map showing 'hot spots' of tool/cut marks. Darker red zones indicate high density and lighter coloured zones represent lower densities



The heat maps clearly represented spatial patterns and densities of the trauma and taphonomic damage provided evidence to corroborate the belief that the postmortem damage occurred following displacement and secondary burial. This demonstrated the useful application of GIS on assemblages of human commingled remains, in managing and representing large amounts of data. The constraint of time, however, was a factor and limited the opportunity to apply the GIS-based approach to all bone elements in this study.

Recommendations

The use of GIS in osteological research and the cross pollination between disciplines has proved to be extremely useful in this study of the complex and large commingled human remains from the Chapel of San Girgor. Certainly, GIS can be time consuming as well as complicated if one is not familiar with the software. Ensuring that the projection used was exactly the same across the board was crucial, otherwise the spatial representation of the polylines could not be visualized, and the heat maps could not be generated.

In this study, using both photos and 3D scans of skeletal material was attempted to obtain PGN files with which polygons were then created. Scanned material was easier to manipulate, however, access to a handheld scanner was not always readily available and mapping eventually relied on the use of photos. The time needed to scan skeletal material other than the femurs was a limiting factor and the future assessment of other bone elements in this collection could be useful for comparative purposes. In addition, if time permitted, and proper excavations and site photographs were available, the use of GIS could allow for two other research options: 1) to connect elements to one another in commingled assemblages and assist in the determination of the minimum number of individuals; and 2) visually represent the position of individuals or skeletal elements within a burial site to understand whether any disturbance had taken place.

Incorporating GIS here, to manipulate, manage, and visually represent vast amounts of data, has demonstrated that the approach can facilitate and lead to more efficient sharing across disciplines. Looking to the future, one can appreciate the amount of data that is collected in the field of bioarchaeology. If used creatively, GIS without question, could be instrumental and of great benefit to osteological investigations both in archaeological research projects and time sensitive development-led projects.

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CHAPTER 7

The archaeological significance of rock cut pits identified in the limits of Ħal Safi and Gudja between 2014 and 2019

Elysia Marie Camilleri Darmanin

Keywords

Rock-cut pits, GIS, landscape, typology, Ħal Safi, and Gudja

Project Aim

The main aim of this study was to study the rock-cut pits at Ħal Safi and Gudja, where the objectives focused on the following:

- To identify if there was a typological preference for the rock-cut pits in the areas of Ħal Safi and Gudja;
- To determine if any type of bedrock was preferred to cut the rock-cut pits;
- To determine whether there is a concentration of rock-cut pits in Ħal Safi and Gudja;
- To see if there is a preferred terrain on which the rock-cut pits were excavated;
- To determine if there is a preferred orientation in relation to how the terrain the rock-cut pits were dug out;
- To determine whether the rock-cut pits found in Ħal Safi and Gudja provide an archaeological context when compared to other archaeological features found in close proximity; and
- To analyse the rock-cut pits that have been discovered on the Maltese Islands.

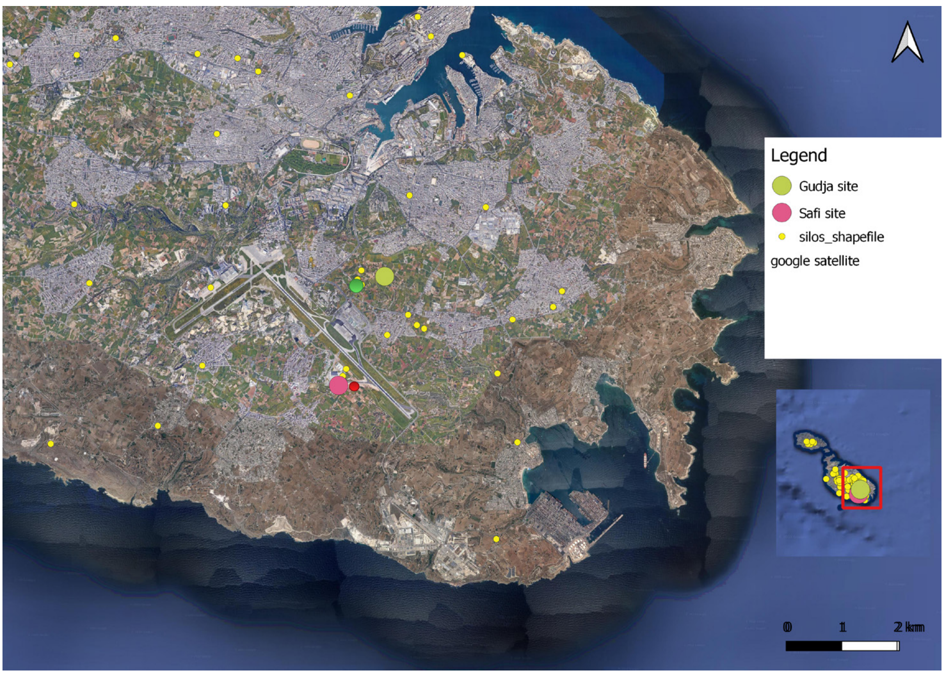
Introduction

This study focused on two sites in the south of Malta, specifically in Ħal Safi and in Gudja. The rock-cut pits that were discussed in this study were uncovered during investigative works. Both sites were development-driven interventions. Furthermore, the rock-cut pits found at ta' Garnaw and at Tal-Karwija (Figure 1) was compared to other rock-cut pits found on the Maltese Islands for a more complete analysis within the aims discussed below. GIS was also used to expand the research to further analyse the data collected from the sites vis-à-vis other rock-cut pits that were discovered. Data generated using a GIS was used with the aim to:

- plot the majority of the rock-cut pits that were discovered;
- plot the discoveries made in Gudja and Ħal Safi;
- identify if there was a preferred terrain on which the rock-cut pits were dug out;
- identify if there were clusters with similar properties; and
- identify if the rock-cut pits were close to a known settlement.

In the second part of the study, apart from the rock-cut pits that were discovered in tal-Karwija and ta' Garnaw, the rock-cut pits that were discovered on the Maltese Islands were also included to create a more holistic approach to this study.

Figure 1: Location of Tal-Karwija site in Ħal Safi and Ta' Garnaw site in Gudja



Source: Database created for this study

Methodology

One source of information was local plans. The information on rock-cut pits was inserted into a database that was created specifically for this study to group the information acquired from various sources. By using GIS, it was possible to sort and manipulate the already existing data to provide insights on the features following the aims which were set out at the beginning (Chapman, 2009). GIS has helped to understand spatial use and the relation and role the landscape has in land use. According to Conolly and Lake, the base maps provided background contextual data and provided a useful spatial framework for archaeological investigation (Conolly & Lake, 2012). However, the authors emphasised that even though the maps generated through GIS were a useful resource of information that presented the data easily for a face-value interpretation, one cannot include and consider the social implications that the society throughout time has had on the landscape being studied. The data generated had to be combined with "ethnographic, historical, environmental, experimental and archaeology" sources to create a balance between the resources used and the results obtained (Conolly & Lake, 2012).

The use of GIS in this study facilitated the distribution of the location of the rock-cut pits together with other features that are close by. This was done by plotting the data on a georeferenced plan of the Maltese Islands. This improved the chance to identify patterns, such as any preferences with regards to the location of features and distances from one another. The distribution maps created provided a more visual insight which on paper might be lost or a longer manual proceeding time.

The data collected from the SCH registers, Planning Authority (PA) local plans, and general research on rock-cut pits were combined and entered in an excel database. The register includes, when available, the site code that was assigned to the site or discovery, the address of the site, X Y coordinates, a brief description of the features discovered on-site, and any available comments. Apart from gathering all the data of different sites related to discoveries of rock-cut pits, this register was then fed into the GIS to generate a point vector layer using the X and Y coordinates from the dataset previously gathered. The Digital Terrain Model (DTM) had a resolution of 1.4m and used the coordinate system of EPSG:23033-ED50/UTM zone 33N. When the registers were inputted into the GIS, sorting of the data within the registers was carried out. The sites were also divided into the Gudja rock-cut pits and the Ħal Safi rock-cut pits. The rest of the rock-cut pits found throughout Malta that are reported in the SCH registers from 2011 onwards, were also added into a different layer. This study focused on two sites that were discovered during development-led monitoring. During research which was carried out from the registers provided by SCH, similar sites were observed having similar discoveries but were found under different circumstances. These are an accidental discovery and an archaeological excavation. It is important to note this point as sometimes the level of detail available might vary depending on the circumstances under which they were found.

When the sites were plotted onto the plan, contours were created within the plan. This step was one of the first exercises. Contours enabled the creation of defined visual aids for areas that are on ridges, flat land, and steep areas by measuring the distance of areas having the same topographical characteristic. After the initial data gathering and input into the GIS, buffer zones of 10m and 100m were created to provide a basic visual map representation of the rock-cut pits from various sites which are in very close proximity.

The slope analysis (SA) function was used because given that the rock-cut pits usually are not visible but are dug out in bedrock, the slope analysis provided more substantial information. SA is usually preferred for use within an archaeology study as part of site location prediction analysis (Conolly & Lake, 2012). The SA was also carried out by using the database that was created from the SCH, PA, and from the general research on the topic. The Aspect function was subsequently used to provide the slope direction. As one needs to consider and assume any possible margin of error with regards the collection of data, aspect can be used in conjunction with this data as an environmental factor to feed into the creation of the map and have a more somewhat holistic map created for interpretation (Chapman, 2009). Aspect is an environmental variable that is considered when producing a predictive model to help in identifying areas that were preferred in this case for the excavation of the rock-cut pits (Nsanziyera et al., 2018).

Background research on rock-cut pits:

The archaeological evidence gathered from SCH archives and the archaeological literature shows that storage facilities very often have a more circular shape. A circular shape is generally favoured against other shapes because it avoids sharp corners. The notion of not having sharp corners stands for any use associated with these rock-cut pits. The same concept of no sharp corners is ideal when using it for grain or for water catchment which are generally the main uses associated with these circular pits.

Storing grain this shape is favoured as it provided better packing of the crop within the storage container and thus removing any possible air which might be trapped between layers once the crops settle after being filled. Removal of air pockets from the pits after they are filled with the produce is essential in the use of these features as it may lead to less silage to spoil (Wilson, 1919). When the cylindrical pits are intended to be used for water catchment, the circular shape is still favoured as it reduces the time for its construction but at the same time would be able to hold a higher volume of water (Brush, 1982). Furthermore, when the lining of the pit follows the contour of the cylindrical shape of the pits, it is more durable as the bonding is more homogeneous and has no sharp edges which very often are the weakest points (Brush, 1982).

As part of the outlook towards rock-cut pits, the location and the significance their positioning had within the community are important. Oyen (2020) notes that there is evidence of reutilization of a 2nd century BC pit was reutilised in Viladamat, Alt Empordá, Catalonia when wine-producing villas were being built in the area. The author suggests that maybe in Roman period Catalonia, when families were moving away from a more centralised culture to a more solitary lifestyle, mimicking previous storage techniques that were proven to have a good success rate for storage of silage, was being adopted. Apart from being a solitary lifestyle, it could also suggest a privatization of land use for agriculture (Oyen, 2020).

Conditions in which goods/supplies are stored are important factors which might help to identify the use of such pits. For example, silage which is derived from different plant mixtures, requires the produce to be moist but with no oxygen (O2) supply. Silage is very often fed to husbandry animals (Falk, 2012). The fact that moisture is needed to store this produce will determine if a pit has lining or not. Given that the Maltese bedrock is very porous, the rock will remain moist, thus providing ideal conditions to store silage. On the other hand, if grain is stored or even water is stored, lining of the pits is important to avoid spoilage of the good or leakage of precious water which was always scarse as the Maltese Archipelago was only dependent on rainwater (Schembri, 1993). When pits are used for grain storage, dung, clay mixed with straw, clay and basketry may be used. When more durable material is used, which Jiménez-Jáimez et al. (2019) have coined the term 'expensive' pit category, concrete, stone and brick are used as lining material (Jiménez-Jáimez & Suárez-Padilla, 2019).

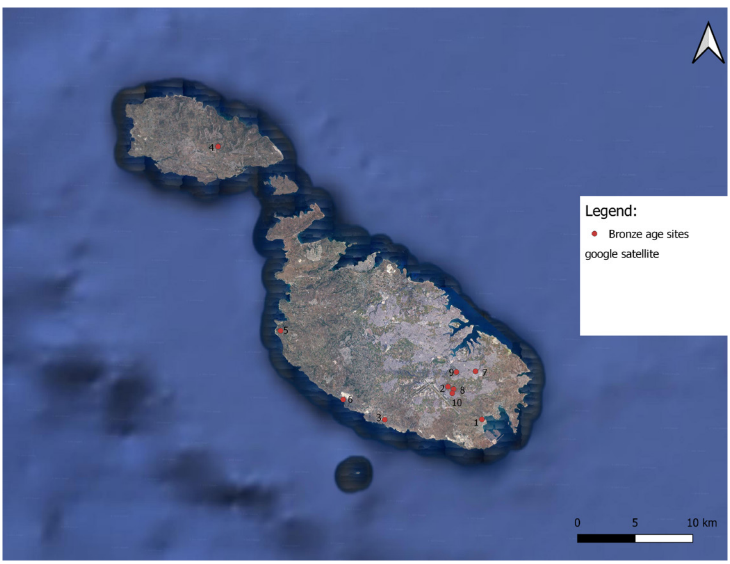
Experiments on the fortified Iberian granary of San Esteve (Olius, Solsonès) which is dated to the 3rd century BC have been carried out (Cardona Colell, et al., 2013). 1000kg of barley was poured into one of the best-preserved silos on this archaeological site. This experiment proved that although some changes had occurred to the grain that was against the walls of the rock-cut pit and next to the opening, most of the grain could be preserved when no O2 is present and when carbon dioxide (CO2) is prevailing. CO2 gas occurs in these conditions due to the respiration of the grain within the pit that absorbs O2 (Cardona Colell, et al., 2013).

Different scholars have attributed different functions of use for these circular rock-cut pits which are more commonly referred to as rock-cut pits. Generally, the function attributed to these features depends on the narrative that most likely the research is trying to achieve by the site being investigated. It is important to note that not enough studies have been carried out to allocate the circular pits with one definite use. However, this would still assume that they had only one function. Notwithstanding any research question that a study might be following, it would be limiting to the research to associate this feature to one usage which is not supported by written documentation. Reviews of various written contributions lean more to associate a generic use of the rock cut pits with the storage of grain or wheat (Trump, 1961), whilst Sagona (1999) argues that rock cut pits may be associated with the dyeing industry.

In a Maltese context, very often, when rock-cut pits are discovered during excavation or an accidental discovery, irrespective of the possible usage of these features, they are frequently attributed to the Bronze Age period. Very few studies to try and date the features have been conducted thus far. However, a recent study conducted by Cutajar in 2019 challenges this dating. In summary, the study showed that in the rock-cut pit in the Karwija Area in Safi, the material culture dates to the 09th century.

The following are some sites where rock-cut pits were discovered during investigations that are attributed to the Bronze Age Period; tal-Mejtin (2), in-Nuffara (4), Borġ in-Nadur (1), Baħrija (5), Wardija ta San Ġorġ (6), Bulebel (7), tal-Ħorr (9), Bir Miftuħ (10), Misqa 'tanks' (3), and it Tumbata (8) (Evans, 1971) (Figure 2).

Figure 2: Location of Bronze age sites as described by Evans



Sources: (Evans, 1971), Database created for this study

With regards to typology of the pits, various approaches were dedicated to the rock-cut pits which essentially use the same form type but with different nomenclature dedicated to the specific shape (Beeching et al., 2010). In the study of pits which Beeching et al. carried out at Saint-Paul-Trois-Châteaux, the following three sub-categories:

1) bomb pits with a spherical tendency;
2) conical with a flat bottom and, in some cases with a neck; and
3) sub-cylindrical pits or pits with very slightly divergent walls.

It was suggested that the three sub-categories are a result of different phases and it was noted that the shape in A3 consistently did not yield any inhumations within (Beeching et al. 2010). The study also puts forward the fact that group of pits which contain similar deposits are spatially located close. This may be linked to the same time of occupation. The contents within the pits from Saint-Paul-Trois-Châteaux were a mixture of inhumations and waste/garbage disposal. It is hypothesized that there is a link between burial rituals and the storage of grain and the importance of women within the society. The role of women within the community is analysed within the context as most of the inhumations found on site are female (Beaching et al., 2010). Despite the in-depth study carried out on two sites and the identification of various typological variations, a specific use to one shape cannot be yet determined.

Another study which tackles typology from which this study was fashioned its interpretation for the different typological variations is the study Prats et al (Prats, et al., 2020) have carried out at north-eastern Iberian Peninsula specifically in Catalonia and Andorra. This study produced two categories of classification

1. closed or converging; and
2. open or cylindrical.

In the areas of study, the authors noted that in Early Bronze Age (2300–1300 cal BC) the ellipsoidal pits were introduced. This accompanies the representative bell-shaped and cylindrical examples which continue to increase in quantity until the Late Bronze Age (1300–750/700 cal BC). Even though the number of pits decrease, the amount per capita of occupation vis-à-vis the settlement remained in ratio with an increase in volume (Prats, et al., 2020). In the Early Iron Age (750/700–575/550 BC), the bell-shaped pits prevailed over other shapes. The period which has produced the most variety of shapes is the Middle Iberian period (450/400–200 BC) which had the spherical shape being the most encountered on settlement sites. Prats et al, have associated the variation in sizes of the rock-cut pits with the developing social complexity of settlements. The more evolving groups of society tended to have increased amounts of silo pits per capita within the site (Prats et al., 2020).

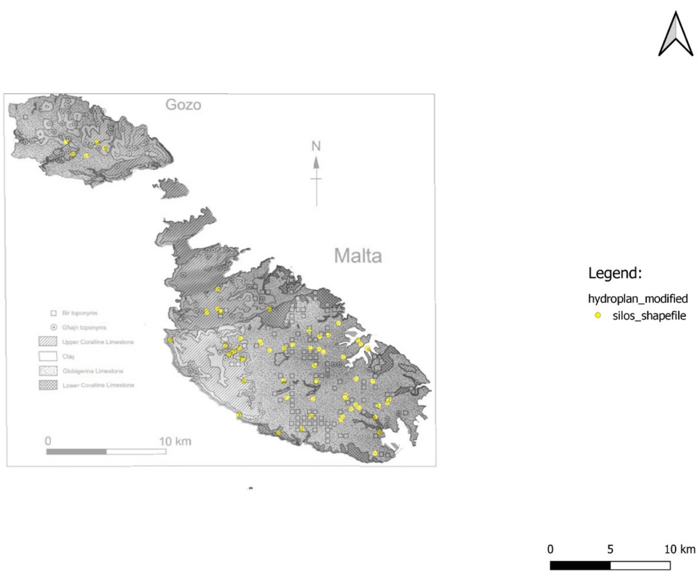
The most common referral to these features is often associated with water collection or grain storage. Nonetheless, Beeching (2010) questions this. He suggests that the use of these pits may well be used as garbage disposal units but also as part of funerary practices in a community (Beeching et al., 2010).

Results and Discussion

Key results emanating of this study are:

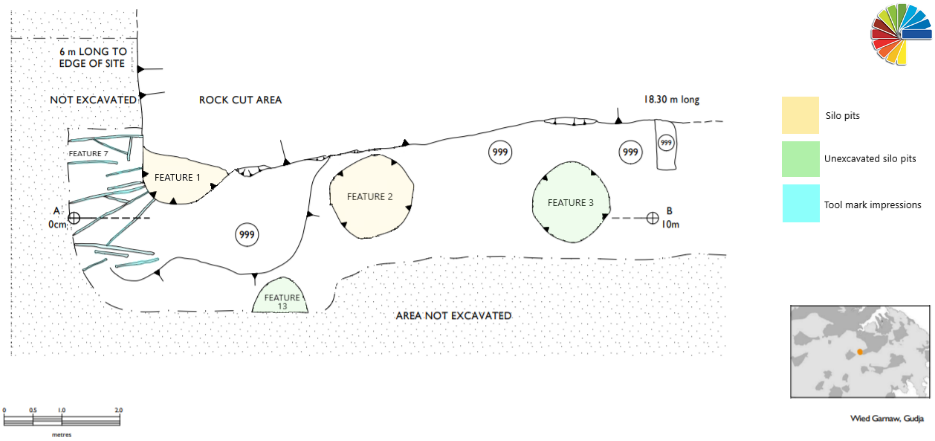
1. The rock-cut pits from both sites which had lining all have other water related features which suggest they were used for water catchment;
2. Different typologies are used for the same site suggesting maybe that given that all had the approximately same opening size, there is the possibility that the shape is determined by the breaking of the bedrock and the size required;
3. In the majority of the sites where rock-cut pits were found, similar features were also found suggesting a pattern of use (Figure 4 and Figure 5);
4. When the plotted rock-cut pits were superimposed on a hydrology plan where wells and springs are marked, Globigerina limestone is preferred as a type of bedrock to excavate such features (Figure 3).

Figure 3: Superimposed hydrology plan



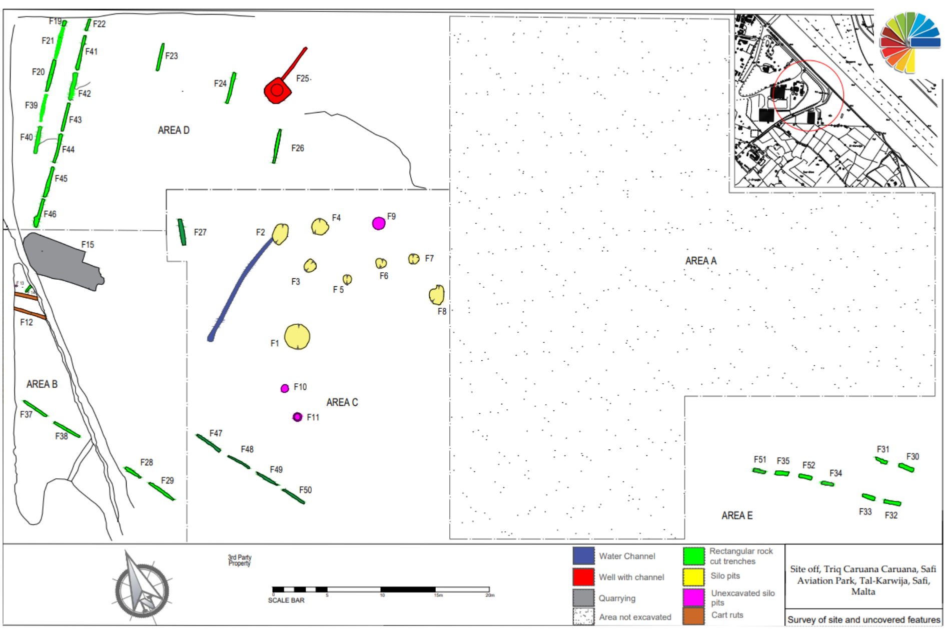
Source: Database created for this study

Figure 4: Plan of Ta' Garnaw Gudja site



Source: SCH archives

Figure 5: Plan of Tal-Karwija Ħal Safi site



Source: SCH archives

The first observation is that 45 of the silo pits are in Globigerina limestone. Even though this type of bedrock is the most abundant type of rock found in the Maltese geological makeup, it is also important to note that apart from being abundantly available, a quality which makes it easier or rather the preferred type of rock in which to rock cut in, is the malleability of Globigerina limestone. Simple tools such as a hammer and chisel can be used to excavate and shape it in a relatively short amount of time. This would have saved precious time which could be dedicated to other tasks in a rural setting.

On the other hand, given that it is so malleable, other factors weigh in that impact negatively Globigerina limestone as it is "very porous with a relatively low tensile strength and high-water absorption" (Rothbert et al., 2007). Therefore a good lining methodology would be required to preserve any water loss if a rock-cut pit is being used as part of a water catchment system. When analysing both tal-Karwija, Ħal Safi site and ta' Garnaw, Gudja, it was noted that the features are dug into Globigerina limestone. Table 4 shows the rock-cut pits from both sites which had lining and no lining. At ta' Garnaw, Gudja, none of the pits excavated (SP12 and SP13) are lined. In the case of the other two pits which were not excavated, no information can be attributed since they were not investigated. At tal-Karwija Ħal Safi site, two did not have any lining, two had a thin layer of cement and the other three, which are interconnected, only have cement repair work within. As at ta' Garnaw site, no information could be given with regards to the lining for the three rock-cut pits which were not excavated during this intervention on site.

The results showcased in the table below might indicate the use of certain pits at some point. Both SP2 and SP3 have water related features truncating into them. SP2 has a water channel at the opening. SP 3 has a circular cut at the bottom which very often is also considered for water catchment as a depositing place for any dirt that is mixed with the stored water. SP5, SP6 and SP7 have provided another scenario. These are the only interconnected pits and have a cement repair. Usually, these repairs are required for water not to seep through the bedrock given that the features are dug into the ever-porous Globigerina Limestone.

Recommendations

Key recommendations from this study:

- From the study of both Tal-Karwija site in Ħal Safi and Ta' Garnaw site in Gudja, when works are carried out without proper monitoring, valuable data which may provide essential data from the deposits found within a feature, are lost. More filtering of sites and site predictions are required by different entities to ensure that the potential archaeology underneath is safeguarded and protected. If the archaeological sites are plotted on GIS, heat maps may be created to enable more accurate site analysis. Future studies may build upon this study by comparing the findings from Garnaw and Tal-Karwija with a site which has similar archaeology. The pits which have similar typologies may be plotted on a GIS to understand any patterns beyond the two towns studied in this research.

- Further investigations of unexcavated features are recommended (given that in both sites rock-cut pits were preserved in situ) to be added to the GIS created for this study with the new data acquired.
- If further investigative works are carried out on the material within the unexcavated features in both sites, more environmental samples should be taken and studied. These would then be plotted on a GIS to identify if there are any patterns.
- The pottery within the present unexcavated features can be analysed and plotted on a GIS with all the known dated material culture from other sites to create various maps to identify any possible pattern.

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CHAPTER 8

Inference from Absence: Addressing archaeological negative data through spatial analysis and topographical studies

Jessica Scicluna Davids

Keywords

Inference, absence, archaeological negative data, spatial analysis, archaeology, GIS

Project Aim

The aim of this study was to derive data from known archaeological sites including discoveries from rescue excavations and undergoing development-driven archaeological monitoring of sites so as to identify spaces which yielded negative data. Various reasons may be attributed to archaeological negative results, including loss from continuous use of the site, war damage, quarrying activities (from ancient times up to the last 30 years) and excavation biases or selected documentation practices.

Introduction

Archaeological landscapes may be challenging to discern primarily due to physical constraints, when they are either buried under sediments or concealed by cities, old or new. While a vast area of unbuilt landscape can be investigated by non-intrusive methods, it would be costly and time consuming to also investigate it through invasive archaeological methods. If the landscape in question is built over, an archaeological investigation covering a desired area may simply be inconceivable due to structures which may be both obstruent and protected due to their cultural heritage value (Fitzjohn and Ayala, 2011). In both scenarios, a cultural landscape remains hidden. In locations such as Rabat, Malta, the reutilisation of the same location for centuries has either erased thousands of years of archaeology or has simply been buried throughout the times. In such cases, one must consider site formation processes and effects from the natural elements as these are usually the determining factors for the survival of archaeological remains. Another important factor to consider is the fact that not all human actions will leave evidence in the archaeological record, albeit being sure that certain activities did occur within a given landscape. Failing to consider and study such aspects will render these human practices to remain imperceptible (Leusen, et al. 2011).

Physical constraints are not the only reason for hidden landscapes. Archaeological biases, methodologies and site managing policies also contribute to conceal cultural landscapes, even during their investigation (Leusen, et al. 2011). Generally, prehistoric landscapes remain undetected due to deterioration, especially if the remains are made of organic materials and due to the reutilisation of the same sites by subsequent occupants The longevity of certain activities and uses of a given site will also affect the survivability of remains in the archaeological record.

Analysing negative evidence is an effective method to interpret the archaeological record. It is not a trend to focus on the absences of a given site. However, such gaps may answer pending questions that may arise. There are three scenarios whereby negative evidence is present in the archaeological record:

- the absence of evidence of an event that did not take place;
- the lack of remains of an event that did happen but did not leave a trace in the record; and
- erroneous for an obscure collection of data which remains undetected (Stone 1981).

Perreault explains how not all human behaviour would leave its traces in the archaeological record as they would not require the use of objects (Perreault 2019). This leads one to address site formation processes to postulate inference within reason and context.

The concept of inference from absence can be closely linked to the notion of hidden landscapes. The modern landscape may hinder the visualisation of intervisibility between known sites and may 'hide' other archaeology in between. This is especially true for sites or entire cities which have been populated and reutilised since their first human occupation. The reutilisation of these sites may conceal or eliminate evidence of use of a specific period. Nevertheless, this does not prove the absence of human activity but may reinforce the fact of continuous settlement. The use of organic materials may also result in loss of evidence due to their inability to survive in most Mediterranean climates. This is the case with regards to the Maltese Islands where severe seasonal fluctuations, between wet and dry climates, results in the accelerated deterioration of organic materials (Renfrew and Bahn 2008). In locations such as Rabat, Malta, the reutilisation of the same location for centuries has either erased thousands of years of archaeology or has simply been buried throughout the times. In such cases, one must take into consideration site formation processes and effects from the natural elements as these are usually the determining factors of the survival of archaeological remains.

In this regard, one must also take into consideration that certain human actions do not leave any surviving archaeological traces and thus would remain 'hidden' from the record (Van Leusen et al. 2011; Fitzjohn and Ayala 2011; Pizziolo and Sarti 2007; Poggiani Keller 2007). Landscapes could be better investigated following the introduction of GIS (Geographical Information System) in the 1990s (Van Leusen et al. 2011) and other scientific methods that allow for non-intrusive analysis. Such methods include Light Detection and Ranging (LIDAR), aerial photography, land surveying, Ground Penetrating Radar and resistivity. These facilitate methods for archaeologists to better understand the landscape before excavation and provide fundamental procedures that could be carried out in areas where invasive archaeology may not be an option. The use of GIS, along with other scientific aids 'forced us to pay much more attention to gaps and biases in our data, and to study formation process of the archaeological record' (Van Leusen et al. 2011

The loss of archaeological remains may simply occur due to excavation methods that may be biased and thus obscure certain aspects of a site (Perreault 2019). Certain methods used may leave out important evidence whilst, lack of experience of archaeologists may result in the loss of data. The research agenda (especially if too specific), budget and time constraints may also affect the collection of data from the site and presentation of results according to the desired outcome of the study (Perreault 2019).

Only one similar research question was found during the research. McLaughlin (2020) explored negative results in Ireland from past watching briefs, in relation to known archaeological sites and the topography using GIS. McLaughlin explored the Irish landscape by creating maps that displayed different aspects of the topography together with the distribution of the negative and positive sites to understand why sites of no archaeological significance appear where they are. He provides information regarding Irish archaeology and monitoring, stating that Irish archaeology is abundant in prehistoric and early mediaeval archaeology. Like Maltese practice, all excavation works (in relation to development and archaeological investigations) in Ireland require a permit and are monitored by qualified archaeologists. He explains that large national projects such as motorways, which were brought about by the infrastructural development, were all monitored. The most significant results were observed in the database for soil types and road works, with the latter described as 'driving the change'. McLaughlin elaborates that 'roads are not independent of the archaeological past' and that the same pathways evolve into modern roads that are still in use in modern times. The short study concludes by stating that principally the landscape and the archaeology correspond to one another, however, sites with negative evidence also emulate this model. Perhaps the most significant argument of this study is that 'modern development patterns and past networks are not independent' (McLaughlin 2020).

Methodology

Mc Laughlin uses a Digital Elevation Model (DEM) to illustrate the changes in the natural terrain. This was one of the shortcomings of the data for this study as the DEM available for Rabat shows the existing levels which are mostly built over, thus not representing the 'original' terrain levels. In fact, the DTM (Digital Terrain Model) of the Rabat AAI was not included in this study as it did not reflect the true natural ground profiles but provides spot levels of the current road surface, which are at times metres above the original natural surface owing to the constant occupation and redevelopment of the area. Even the contour map was found to be misleading as some of the contour lines were found to follow buildings rather than the terrain. A DSM (Digital Surface Model) for 2018 was used for this study.

The methodology consisted of the creation of the geodatabase on a GIS platform. Data of the known archaeological sites was generated from the Planning Authority's (PA) map server and the Superintendence GIS platform. These sites were plotted onto five maps ranging between 1895 and 2018, provided by Dr. Gianmarco Alberti (University of Malta) and the Planning Authority; each map showing discoveries made up until the publishing date of each map. The known sites were then plotted according to their function onto the 2018 orthophoto:

- Agricultural
- Industrial
- Military
- Funerary
- Structural Remains and Deposits
- Unclassified
- Multi

The location of WWII shelters was also plotted together with the 25m constraint zone around each known site as per current SCH monitoring parameters. These indicative constraint zones aid Superintendence officials in their daily work in their judgement to justify monitoring requirements or vice versa. Due to Rabat being immensely populated with archaeological discoveries, the constraints usually overlap one another.

Data for the negative sites was collected from monitoring registers at the Superintendence and from the PA's Eapps Portal. A total of 1,981 planning applications spanning over the last 30 years were reviewed in depth to identify the possible reason for absence. During this exercise, 15 categories for negative data were established, however eight of these provided a higher probability of a negative result:

- Negative Sites (as established from the CHSR)
- No Information & ground disturbance
- Reply issued by SCH, not listed in the Cultural Heritage Services Register
- No SCH reply despite proposed ground disturbance
- Sanctioning & ground disturbance
- General Note
- No Complaint Cases/ Heritage Compensation
- Existing Basement

These were plotted individually and on a merged layer to explore the data. A 25m buffer zone was created around each archaeological site using a 'count' tool to establish the number of negative points within each constraint. The results were divided into five classes represented by graduated symbols to be visually apparent. The classes which contained more than five negative occurrences (maximum negative occurrence within a 25m buffer zone was 11 sites) were studied in detail for the analysis. The permits within each cluster (totaling to circa 2,000 applications) were analysed to determine the possible reason for absence. The proximity of positive sites to negative spots was illustrated using the 'distance to nearest hub' tool.

Results and Discussion

The results obtained from this study showed that, despite Rabat being one of the richest areas with archaeological discoveries on the islands, it also has a high negative ratio as there are twice as many cases of negative occurrences (884) than positive sites (436) (Figures 1 and 2). Figure 1 shows all the sites which for one reason or another (as explored during this study) did not yield any archaeological remains in an area which is abundant in discoveries as illustrated in Figure 2. It must be emphasised that, although not all 884 sites have been monitored and thus one cannot verify the presence of archaeological remains, it is concerning that such sites within proximity of important remains have not yielded any archaeology, or worse, have not been monitored. As environmental and cultural awareness was being brought to light in the 1960s and eventually sustained by law in the 1990s (Boissevain 2000), NGOs and government agencies were set up and given the ability to regularise and maintain environmental and archaeological monitoring. This led to a sharp rise in archaeological discoveries since sites in sensitive areas such as the Rabat AAI were closely monitored, more so in the last 20 years.

Figure 1: Total Negative Sites within the Rabat AAI

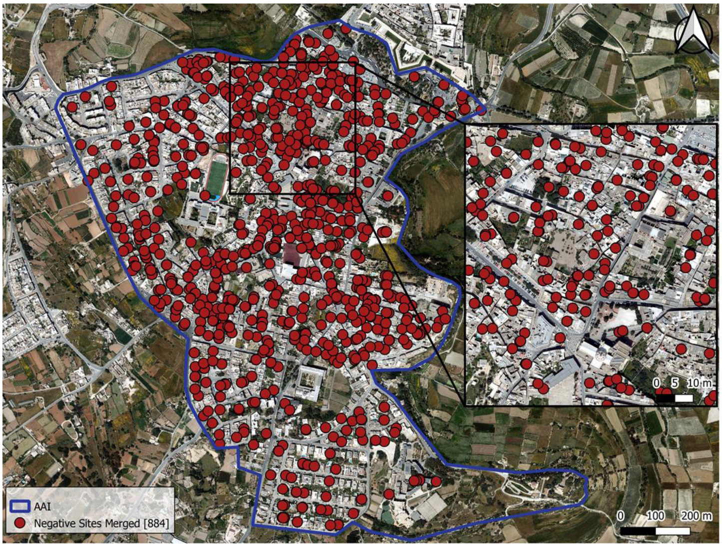
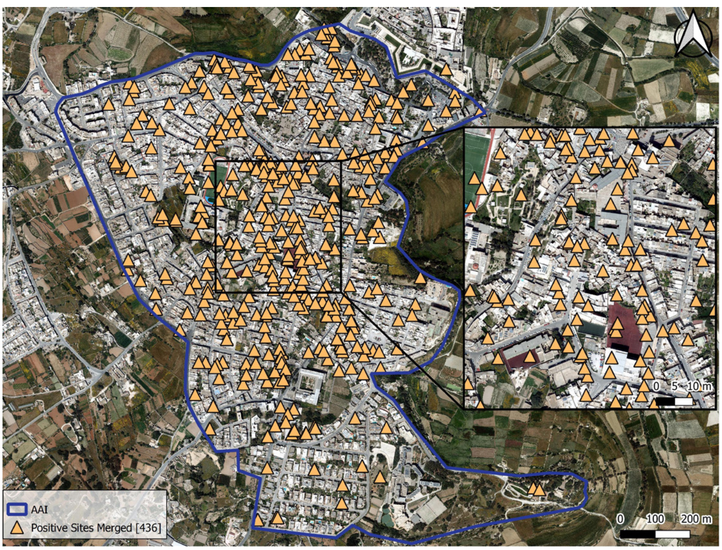


Figure 2: Total Positive Sites within the Rabat AAI



The results were generated from the analysis of 10 different zones within the Rabat AAI, each with a high negative case count in relation to archaeological discoveries within a 25m radius (blue gradient buffer zone). Figure 3 presents the findings of one of these zones - the area around Triq il-Kulleġġ. Triangles were selected to illustrate the known archaeological sites. Different colours were used to differentiate typologies. The brown broken line illustrates the plan of World War II shelters. The dots represent the sites where ground disturbance works were carried out but did not yield any archaeological discoveries. The colours illustrate the possible reasons for the negative results. Each cluster identified in the 10 different zones was analysed (Figure 4).

Figure 3: Triq il-Kulleġġ Clusters

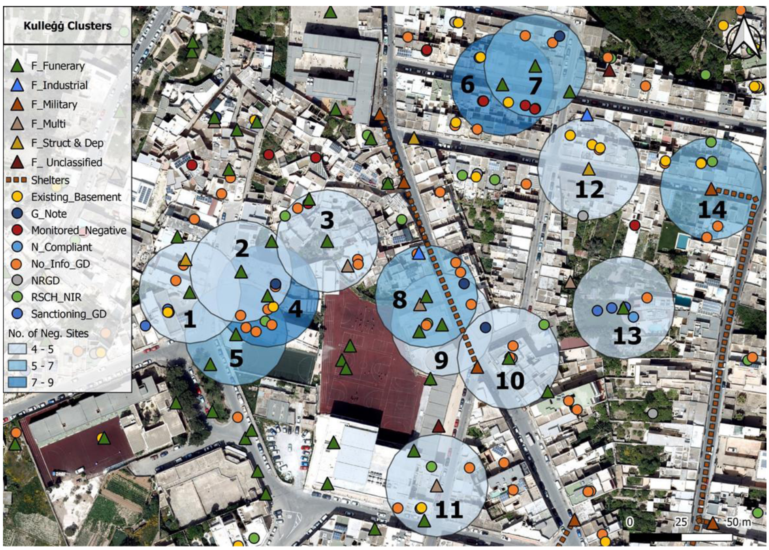
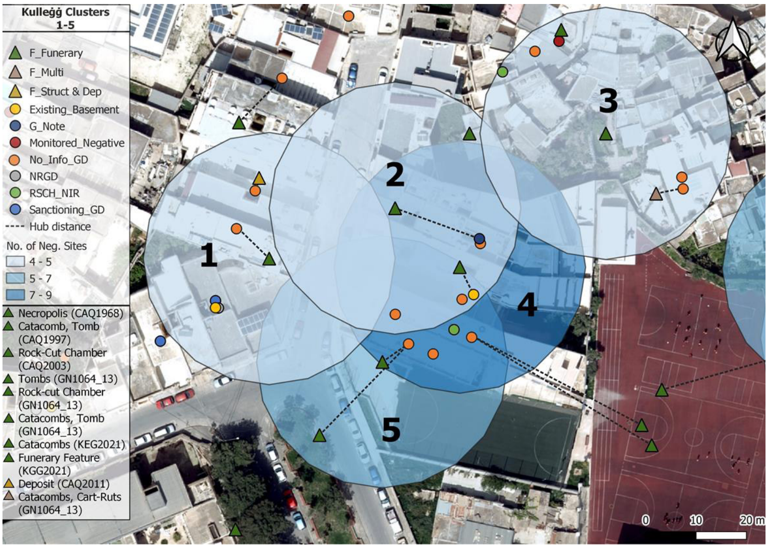


Figure 4: Triq il-Kulleġġ Clusters 1-5



The PA permits that fell within the 25m buffer zone were consulted to understand their case history. Some cases had existing basements or were built prior to the implementation of archaeological monitoring, thus providing a reason for the negative results. The case files of sites which were monitored but still did not produce any archaeological discoveries were also analysed to determine if there were any factors which may have contributed to a loss of data, such as human error or non-compliance with SCH instructions. Figure 4 presents an example of a group of clusters within Triq il-Kulleġġ. The darker blue gradient suggests a larger number of negative sites within one buffer zone. Further to the positive and negative sites shown by triangles and dots explained in the point above, each positive site is listed on the plan with its relevant site code or scheduling government notice.

In general, the results presented displayed the lack of prehistoric remains in the archaeological record. One of the causes that may account for this is the lack of post-excavation pottery studies and cultural material that is collected from development-led archaeological work. Another possibility is due to personal biases, methodologies, and the inability of some archaeological service providers to identify stratigraphy. Certain remains such as prehistoric domestic huts or temporary sites may be inconspicuous and are often a few centimetres deep and made of compacted soil, torba, clay and possibly mudbrick. These may easily be confused with agricultural soil or decomposed limestone. Apart from this, there is a general misconception which is also held by some archaeological service providers that archaeology is only rock-cut, which albeit easier to detect, it is certainly not the case. Archaeological soft deposits and/or structural remains are usually present above bedrock which in some cases have been overlooked, giving rise to sites that result in negative evidence. An example of such varying archaeological remains has been discovered at the Domus in Rabat.

GIS tools enabled the superimposition of different maps as well as extraction and sorting of data according to typology and date of discovery. The 'count' tool was crucial during the analysis part of this dissertation as it created the parameters of the in-depth studies.

The use of constraint zones and their 25m buffer seems to be justified, although these often overlap and almost cover the entirety of the Rabat AAI due to the high frequency of archaeological discoveries. The policies that are in place to safeguard the archaeological heritage prove sufficient though participants in the process should respect and honour such obligations as non-compliance amounts to loss of data. By constantly updating the date, site prediction and monitoring improve, thereby providing a better chance for the concept of hidden landscapes to be brought to light and unknown sites being protected by preventing unmonitored or unnecessary development-led excavations.

As from 2019, the Superintendence increased its vigilance and enforcement with regards to archaeological surveillance as well as updating its legislation including better provisions for charges, administrative fines, compromised penalties, heritage obligations and compensation, which have further lessened the number of non-compliant cases as reported in the SCH annual reports (2018-2021) (Cultural Heritage Act, 2021). A further three categories still cannot be adequately addressed (sanctioning and ground disturbance, existing basement) as again, these are heavily dependent on compliance by the applicant and/or the architect, and finally, monitored with negative results.

Recommendations

Key recommendations of the effort are:

- Owing to time constraints, certain areas of the study were engaged with succinctly but would require further studies. One of the main topics is the concept of hidden landscapes through topography. Since the topography is not uniform throughout a given space, it had to be taken into consideration to fully understand the location of archaeological finds. The hidden landscape analysis is not two-dimensional but three-dimensional due to the nature of the topography, although the latter is mostly hidden under the present built urban fabric. This is especially manifest in the Rabat AAI since most of the area is built over and thus does not reflect the 'natural' topography. Since landscapes are 3-dimensional and in the case of Rabat is mostly hidden under the built urban fabric, an ideal analysis would require non-intrusive instruments such as a Ground Penetrating Radar to scan vast areas without compromising or disturbing sealed contexts. Another invaluable tool that would facilitate the duties of heritage officials and planners, is to plot the actual archaeological discoveries surveyed on site onto a GIS database with attribute information, instead of being illustrated as dots on a map.

- Another gap that should be addressed is the study of soil/environmental samples. Such studies would provide information on landscape use, especially in sites which were used for grazing, agricultural purposes, pathways, and other activities which may not leave traces in the archaeological record (Wilk and Schiffer, 1979). Collaborative effort between local entities may start to address this matter, although it would also require a specific long-term research agenda and related resources.

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CHAPTER 9

Were the defences of Malta adequate to repel an invasion during the Second World War?

Kurt Farrugia

Keywords
Military, History, Malta, Second World War, Pill box, defences, invasion, Operation *Herkules*

Project Aim

The aim of this project was to use spatial analysis to determine whether the defences on the Maltese Islands were enough to repel any attempted invasion by the Axis Powers during the Second World War. Operation *Merkur*, the invasion of Crete, was used for comparison purposes in this research.

Introduction

The German High Command considered invading Malta to stifle operations from there by the British, which were sinking Axis shipping destined for North Africa, hindering the latter's war effort. In the event that the North African Campaign was to be lost, Malta would still have posed a threat to the Axis efforts in the Mediterranean (Schreiber, Stegemann, Vogel, 1995, p. 528). In February 1941, Adolf Hitler, as the Supreme Commander, overruled this recommendation and postponed the invasion of Malta in favour of the invasion of Crete, believing that Crete had better advantages than Malta for the Luftwaffe, the German Air force (Holland, 2003, p. 21), especially in safeguarding the Greek mainland and Aegean Sea routes (Blau, n.d. p. 120). However, Malta's location in the central Mediterranean proved effective in attacking Axis shipping, so much so that after the war, General Erwin Rommel, Benito Mussolini and Field Marshal Albert Kesselring all claimed that the failure to occupy the island was a fundamental mistake.

Britain also had much to lose if Malta was lost to the Axis powers. Its possessions in the Mediterranean were few, and to preserve its interest in the area, its naval strength and bases that could harbour the fleet needed to be retained (Air Historical Branch, n.d., Chapter 1). German efforts to neutralise the island solely through aerial bombardment only had short term effects. Each time, the island was re-armed in little time.

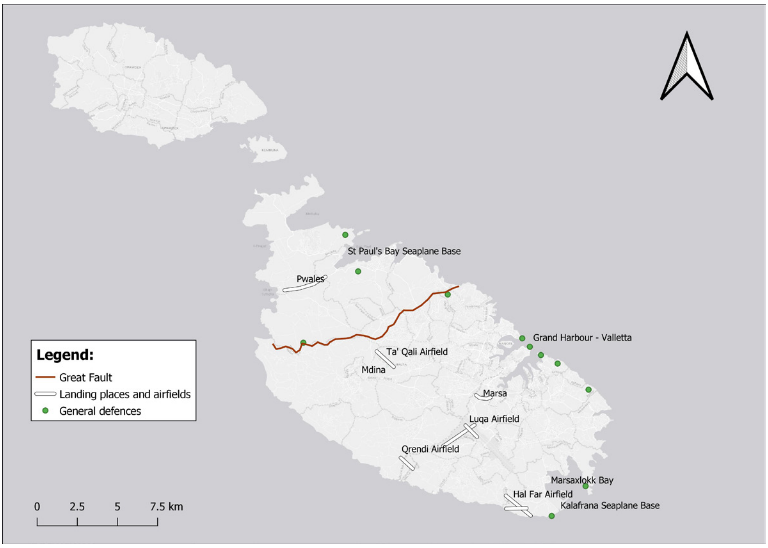
Malta's defences

At the outbreak of the Second World War, Malta was positioned far from the hostilities, as the Mediterranean Sea was surrounded by either neutral or Allied-occupied countries. This all changed in 1940 when Italy entered the war in June 1940, and France capitulated 12 days later (Hogan, 1978, p. 25). In 1935, Malta was badly defended, with just 12 anti-aircraft guns. These were increased to 24 during the Abyssinian crisis (Forty, 2003, p. 46). During the same time, the first concrete pill boxes started being constructed. In 1939, at the outbreak of the war, Malta had been promised 112 heavy anti-aircraft guns located in specifically built batteries, 60 light anti-aircraft guns intended for the defence of airfields, fighter aircraft, balloon barrages, mines and other equipment. (Holland, 2003, p. 26).

However, their delivery failed. When the war broke out the British concentrated their defences elsewhere due to the neutrality of the Mediterranean Sea. In fact, when Italy declared war, Malta was defended by only 34 heavy anti-aircraft and 22 light anti-aircraft guns, alongside a handful of obsolete aircraft (Forty, 2003, p. 34, Holland, 2003, p. 28). However, by the Spring of 1941, the defences had been improved substantially, with heavy anti-aircraft guns numbering 104, whilst there was still a small number of light anti-aircraft guns to defend the airfields. Within a year, by Spring 1942, the number of anti-aircraft guns had been increased considerably to cover any potential landing ground and strategic locations (figure 3), whilst the number of troops stood at 30,000 (Churchill, 1950a, p. 308).

The pill boxes were also constructed in phases. Initially their construction started during the Abyssinian crisis, however, the construction of holistic defences started in 1938, lasting until 1942 (Borg, n.d., p. 47) (figure 2). These were arranged into three categories – beach-posts located on the shore, defence posts formed a second line of defence, whilst the reserve posts formed the last line of defence. Beach defences also included lines of barbed wire, anti-invasion obstacles placed on the seabed, as well as coastal artillery (Figure 1).

Figure 1: A GIS generated map showing the general defences in Malta during the Second World War



Operation *Herkules*

Field Marshal Albert Kesselring appointed Commander in Chief South in September 1941, insisted on the occupation of Malta to stabilise the Mediterranean situation, as Malta was proving to be a thorn in the Axis' efforts to supply troops fighting in the North African Campaign. Operation Herkules, the potential invasion of Malta, never materialised, as the German High Command preferred neutralising the island through aerial bombardment rather than invasion, to avoid a repeat of the losses incurred in the invasion of Crete, Operation Merkur, whilst also believing that their allies, the Italians, were not up to the task of leading the seaborne invasion of the Island. This threat of invasion resulted in Malta receiving the necessary equipment – anti-aircraft guns, aircraft, ammunition, to fight off any attempts of invasion, as well as any aerial bombardment. The Italians, rightly so believed that Malta was fortified like a hedgehog (Douglas-Hamilton, 1981, p. 117).

Methodology

Defences that existed in Malta during the Second World War were researched using historical surveying sheets and literature on the subject that included mapping of the same. Many of the defences were identified on 1960s surveying sheets and maps, as they were clearly marked and labelled. Yet, from literature on the subject it was evident that by the time that the survey sheets were drawn up, some Second World War defences, mainly some pill boxes towards the north of the island, had been demolished to make way for modern development. Literature on the subject was quite adequate, with missing data from the survey sheets and maps easily identified. It was noted however, that geographic data on the subject only consisted of small line maps of the defences found in literature on the subject, such as in Rollo, (1999). This data then had to be compared to larger surveying sheets to try and pin-point the location of the defences. In the instances that exact locations could not be determined, the locations of the pill boxes were not plotted.

The main defences – pill boxes, heavy anti-aircraft batteries and other fortifications in use at the time, were plotted on a Geographical Information System (GIS). For each pill box, a buffer of 500m was included, corresponding to the approximate firing range of the weapons available to the soldiers manning the posts. This relates to the potential killing zones. Hence any invading enemy troops coming within this range were under threat of being shot (Figure 2).

However, the GIS maps lacked plotting of mobile defences, such as Light Anti-Aircraft batteries, which were mainly concentrated around airfields. No cartographic references for mobile defences were found. To make up for this lack of information, the airfields in operation at the time were included. The location of the airfields was sourced from survey sheets. Similarly, the plotting also lacked the distribution of field artillery that was placed at strategic locations around the island in defence against a potential invasion. Due to their mobility, such artillery was not static and were moved in different locations according to necessity. The plotting onto a GIS of Second World War military defences seems to be a first, as no such other projects were traced during the research.

Results and Discussion

Key results of this project are:

- A major significant difference was the preparedness state of the islands. In the Cretan scenario, although military intelligence had been pointing towards a potential airborne invasion, the British failed to prepare the required defences to repel an invasion. On the contrary, Malta was heavily defended. As indicated in the GIS plotting of defences (Figure 4), all potential landing zones were covered by defences, including runways, harbours and bays.
- The spatial analysis indicated heavy concentrations of defences (Figure 4), consisted of coastal guns (Figure 1), anti-aircraft guns and batteries (Figure 3) and pill boxes (Figure 2). Pill boxes were planned in three lines, with the aim of having three stages of defence against any invading infantry troops. The strategic location of these defences, together with the effective range of the weapons used

within these defences, which was set to approximately 500m, provided very good killing zones, which at times overlapped with killing zones from the next pill box. All this, together with the camouflage of these structures, would have made any attempts at invasion a huge challenge for enemy troops. The pill boxes plotted amounted to around 85, which were still visible in the 1968 survey sheets of the islands. Other pill boxes are known to have existed; however, their location was not traced. In this regard, Figures 2 and 4 which included the plotting of pill boxes are not to be construed as exhaustive.

- The heavy anti-aircraft batteries were concentrated in defending the strategic areas of the island – airfields, and the harbour areas (Figure 3). The spatial analysis indicated that these provided the first line of defence against enemy aircraft, as the mobile light anti-aircraft guns, as well as other field artillery were placed according to exigencies, such as within the confines of airfields, and other strategic locations. Other coastal defences, such as gun emplacements and submerged anti-invasion implements, protected potential landing zones and the mouths of the harbour from any naval attacks.
- Whilst the Axis forces may have had an advantage over the British with regards to the troops for the planned for the invasion of Malta, any attempt at invasion may have resulted in huge losses for the enemy troops in view of the heavy defences of the island, which apart from man-made defences and equipment, the landscape was rather unforgiving, and at an advantage to the garrison troops. The parcelling of the countryside into small allotments divided by stone walls was not ideal for an airborne invasion.
- The plotting of the average effective range of weapons for pill boxes provided a good indication of the killing zones, and strategic location of the pill boxes, together with the effective range of weapons used would have given the British and Maltese troops an advantage over enemy troops. The strategic location of these defences, together with the ballistic range of the weapons used within these defences provided very good killing zones, which at times overlapped with killing zones from the next pill box, that formed a very dangerous passage to any enemy troops (Figure 2).

Figure 2: A GIS generated map showing the pill boxes in Malta during the Second World War

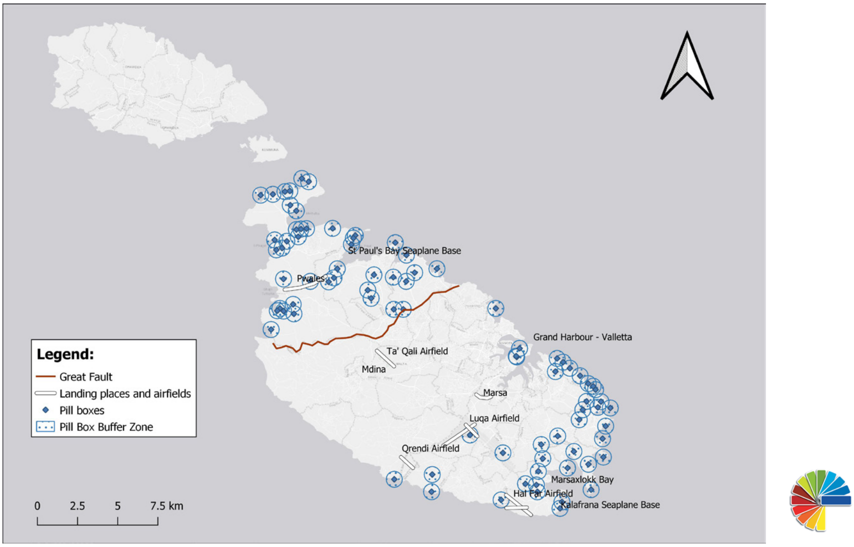


Figure 3: A GIS generated map of the heavy anti-aircraft batteries in place in Malta until 1942. Each battery consisted of 4 guns, however, batteries with fewer guns are known. Light anti-aircraft guns are not indicated as these were mobile and had no fixed installations. These were placed around the landing places and airfields and in strategic points around the Grand Harbour

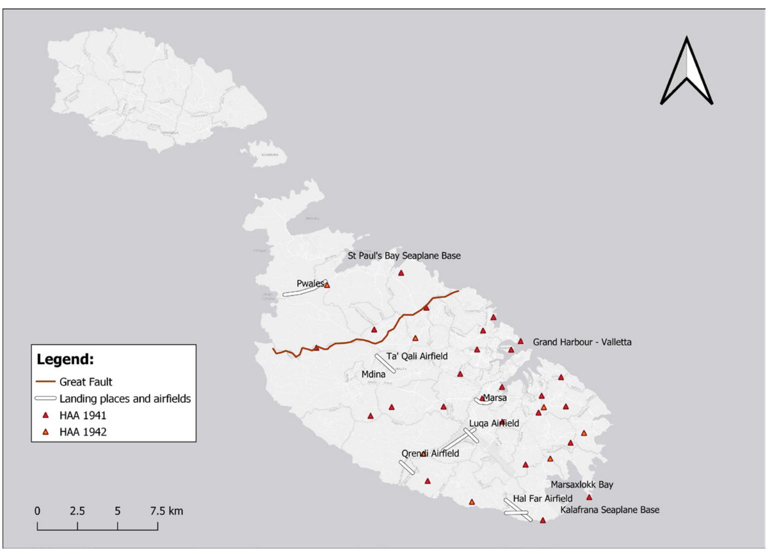
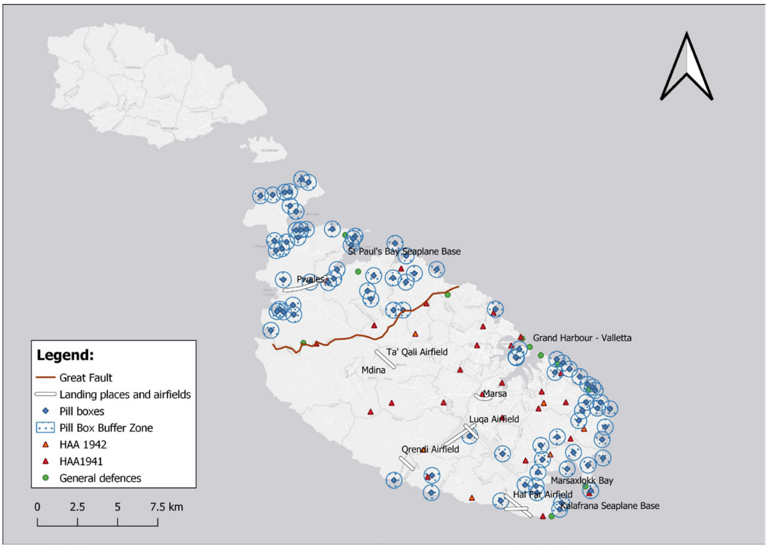


Figure 4: A GIS generated map showing all the defences in place in 1942, the time that Operation Herkules was planned. As explained in Figure 2, the pill box distribution is not complete, as there were more pill boxes at the time. Evident is the lack of defences on the sister island of Gozo. Defences were only constructed on the island in 1943 with the construction of an airfield in preparation for Operation Husky.



Recommendations

Key recommendations of the effort are:

- A terrain analysis of the island during the Second World War. This research clearly indicated that the main defences against ground troops were located towards the north of the island. A terrain analysis would be essential in determining the terrain of the island, and which areas were inhospitable and inaccessible to the enemy, hence providing natural defences. With regards to an airborne invasion, which apart from paratroopers would also include glider aircraft, would require flat plains, which Malta had very little of. Whilst the island was characterised by hills and valleys and the natural landscape is predominantly garigue, open fields were parcelled and divided with rubble walls, which also impeded any aircraft from landing. A more ambitious project would be the plotting of the areas that were parcelled by rubble walls.
- Further analyses on the subject may include the analysis and plotting of all the existing defences during the Second World War, with special attention to mobile

anti-aircraft guns and field artillery, should such information be available.

- Permanent installations, such as underwater anti-invasion implements as well as barbed wire lines also provided essential defence mechanisms. The latter were usually found on rock coastlines. Further research into these elements would present a holistic picture of the defences.
- Another interesting element in the discussion of the defences, especially for anti-aircraft defences, is the assessment of the effective ranges of the guns, as well as the identification of the location of the enemy aircraft crash landing sites, because of anti-aircraft fire. It was estimated that anti-aircraft guns recorded around 230 hits during the entire course of the Second World War. Such a study would identify the hot spots of enemy activity, and which guns were the busiest in terms of enemy action.

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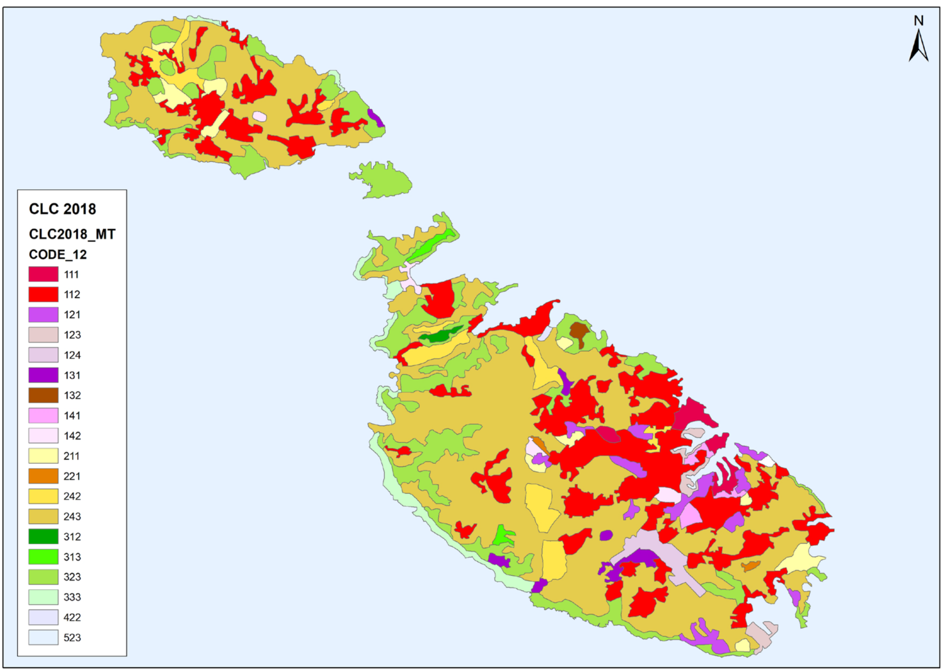
Pivot II

Social Wellbeing Domain



CLC2018

CHAPTER 10

Incorporating Geographical Information Systems (GIS) to improve crime analysis and intelligence-led policing, by law enforcement authority in Malta

Charlot Casha

Keywords

Crime, crime distribution, theft, crime scene investigations

Project Aim

The use of crime mapping through Geographical Information System (GIS) tools has facilitated the detection of crime trends and patterns, through spatial and temporal analyses on digitally pinpointed generated maps (US Homeland Security, Science and Technology, 2013). Considering that all decisions and every solution in the Law Enforcement and Criminology area are based on analysis, studies and evaluations, analysts perform crime analysis to improve operations, investigate crimes committed and make predictions to reduce crime. This multi-dimensional capacity enhances the availability of spatial data to non-GI experts who may be able to interpret the data through maps and graphs (Al Fareed, et al., 2008).

Wang (2012) argues that GIS goes beyond data mapping and its use within the Law Enforcement area has enhanced the crime mapping to a powerful analysis and decision-making tool. GIS technologies may be effective in various areas of crime investigations and prevention, from GPS and mobile phone tracking, to identifying hotspots, to forming hypotheses and predictions, to disseminating 3D and virtual scenarios. Considering that all decisions and every solution is based on analysis, studies and evaluations, in the Law Enforcement and Criminology area, analysts perform crime analysis to improve operations, investigate crimes committed and make predictions to reduce crime.

This study aimed to develop a GIS-based crime analysis methodological framework, for the improvement of Malta's Police Force decision-making process. It focused the primary investigation on the basic framework needed of a law enforcement entity, to introduce a GIS based solution that strategically assists the decision-makers in developing an advancement, from reactive enforcement to proactive policing. In this regard, the study researched models of existing spatial crime analysis solutions and explored a series of statistical and spatial analysis.

This study area consisted of Malta and its sister islands Gozo and Comino, having a total residential population that reached 514,564 by the end of year 2019 (NSO, updated 2021). The Maltese islands have a total area of 316km^2 and lie 93 km south of the Italian Island of Sicily and 288 km from the nearest point of the North African mainland. The National Statistics Office of Malta (NSO, updated 2021) estimates that the population has increased by 19.45% from the year 2010 to year 2019, where the population living in Malta reached 514,564 of which 248,802 are female gender and 265, 762 are males. This research focused only on the crime category 'Theft' and its sub-categories. Nevertheless, the same procedural methodological framework may be utilised to all crime categories both holistically as well as independently. The data used was gathered through official requests or online sources.

Introduction

This study took into consideration various criminal behavioral theories and the legal aspect of the theft category of crime, so that the author might better understand the necessities of the evaluations of the crime situation from a geospatial perspective. This study transpires that the five behavioral theories; Rational Choice Theory (Homans, 1974); Crime Pattern Theory (Brantingham & Bratingham, 1993); Routine Activity Theory (Cohen & Felson, 1979); Broken Windows Theory (Wilson & Kelling, 1982); and Environmental Criminology Theory (Brantingham & Bratingham, 1993, and Wortley & Townsley, 2016), may help the crime analyst and the law enforcement decision-makers to understand certain crime patterns and situations.

The author notes that just like investigative methodologies, there are no standard solutions or models for crime data collection and/or crime analysis. It depends on the necessities and the resources of the law enforcement entity. The tactics will adjust according to the needs of the organisation's state and in parallel with the respective domestic laws and judicial systems. However, the International Association of Crime Analysts (IACA) defines crime analysis as a profession and process in which a set of quantitative and qualitative techniques are used to analyse data valuable to police agencies and their communities (Threat Analysis Group, 1997-2021).

This study acknowledged the problem that police data might have in the numbers of the statistical data collected from the police reporting system, where data may not be accurate due to what Biederman and Riess (1967) defines as the dark figure of crime. Biederman and Riess (1967) explain how the unreported crimes are considered as cases that are not registered in any way by law enforcement entities; therefore, resulting in unrealistic scenario and unprecise statistical analysis. Formosa (2007) argues that people tend not to report crimes due to lack of willingness or due to a fearful element. A study conducted by Tolsma, Blaauw and Grotenhuis (2012) describes how anonymity increases the chance of someone to report a witnessed or experienced crime.

Hirschfield (2001) describes how GIS enhances and facilitates the support in decision-making. Seven areas were identified in the respective study by Hirschfield (2001) and categorised as following:

- identifying strategic priorities and making operational decisions;
- producing audits and strategies in order to prevent crime and disorder in an area;
- setting up coordinators and project managers to develop partnerships for sustainable crime reductions;
- studying causes and prevention of crime;
- tracking changes of crime in neighbourhoods;
- monitoring conditions in business operation areas; and
- predicting safer places to live and invest in.

Observations transpired that several law enforcement online portals offer from zero to minimal interaction to the public in a Spatial Data Infrastructure (SDI), better known as Public Participatory GIS. Other portals tender complex querying tools but exhibit an overall jumbled display that easily causes confusion to the public domain.

Hotspots policing

In the United States of America, hotspots policing emerged through theoretical, empirical and technological innovations in the 1980s and 90s according to Weisburd and Braga (2003), and field exercises resulted that concentrating on hotspots, the police managed to reduce the numbers of crime offences and disorder (Weisburd & Braga, 2003). Generating Hotspots enhance the knowledge about how a number of same offenders are responsible for a number of criminal cases and that a number of same victims suffer from criminal activities a number of times (Ratcliff, 2008). The effectiveness of the hotspots policing approach has strong empirical support. Sherman and Weisburd (1995) used computerised mapping of crime to conduct a hotspots patrol experiment in Minneapolis. The study through the experiment in Minneapolis, found that there were significant reductions in crime calls and disorder observations, in a ten-month period by doubling the police patrols for the experimental sites which were previously identified as hotspots (Weisburd & Eck, 2004).

Nevertheless, Hotspots policing approach may be considered as less useful if crime is consequently displaced to another nearby place. Weisbud and Eck (2004) argue that crime displacement is complex to measure and is also debatable; meanwhile they confirmed that studies in connection with the hotspots experiments, revealed there was an immediate geographical displacement during the hotspots policing. They continue by arguing that in the Jersey City Drug Market Analysis Experiment (Weisburd & Green, 1995), the Beat Health study (Green Mazerolle & Roehl, 1998), and the Kansas City Gun Project (Sherman & Rogan, 1995), not only no displacement of crime was recorded, but it transpired an improvement in the nearby areas (Weisburd & Eck, 2004).

Geographical Weighted Regression (GWR)

The Geographical Weighted Regression (GWR) analysis model is capable to shape and quantify significant non-static variation through independent variables (Fotheringham, et al., 2002).

Study by Yoo, et al. (2017) resulted that the GWR is more efficient than other regression methods for analysing non-stationarity of crime and concluded that the influence of certain factors on crime differs by location. Crime analysis by GWR model significantly assist to the creation of policies addressing local area characteristics to prevent and deter crimes (Yoo, et al., 2017).

Methodology

The methodology commenced by the collection of statistical data from the existing MPF crime reporting system, related to the theft crime category in Malta and its sub-categories. The data provided by the MPF, included all the 'Theft' and 'Attempted Offences' cases that were reported and recorded in their respective system from the year 2010 till the year 2020 bearing a total number of 90,370 cases. The list of data also included the month and the address of the case up to the street level, as well as a sub-category of the crime of theft as recorded in the MPF System.

Due to the large amount of data provided (consisting of 21 sub-categories and over 90,000 cases), the author reduced systematically and rationally the data as clarified hereunder by:

- removing the attempted offences from the list;
- sorting the data by year and extracting all cases from alternate years 2010, 2012, 2014, 2016, 2018 and 2020;
- the data was manually checked for quality; data with missing information (with

no address) was eliminated, and consequently cases were reduced to an amount of 44,584 cases; and

- sorting systematically the sub-categories to reduce the number of sub-categories to nine. The author considered and based the sorting on the type of offence and/or the type of the target as listed in Table 1.

Table 1: New sorted sub-categories and counts

	Sub-category	Number of cases
1	Armed Robbery	173
2	Bar & Restaurants, Hotels & Retail Outlets	8,895
3	Factories, Building sites, Farms & Fields	1,915
4	Offices	452
5	Pick Pocketing, Mugging, Snatch & Grab, Others	13,312
6	Religious sites & Government Buildings	221
7	Streets & Public Areas, Beeches	3,767
8	Vehicles & Sea Crafts	10,764
9	Residences	5,085

Eventually, after the data curation process, the number of the new assorted working dataset for the exercises in this study aggregated to 44,854 cases.

In this study, the primary data that was acquired from the MPF did not include the coordinates of the addresses provided, and due to ethical concerns, the data included addresses up to street level. Therefore, the data that consisted of 44,584 localities had to be georeferenced. The author opted to use the geocoding service provided by the online open-source Google Sheets; 'Google Add-on: Geocode by Awesome Table'. The free version allows one to geocode up to one thousand (1000) addresses per 24 hours. The Addresses from the manipulated data were inputted in the online Google sheet and then geocoded automatically accordingly. It is to be pointed out that the addresses are identified by the system in Maltese Language and not in the English version. The Geo-referencing Projection for the data used was set to EPSG 4326-WGS 84-UTM-33N.

The study applied random manual checks to check the quality of the geocoded data. The checks consisted of randomly picking approximately fifty (50) random coordinates per one thousand (1000) cases to sum up for a 5% sample; the coordinates of the geocoded samples were inputted in a hybrid google map, and the addresses were manually verified for accuracy. This exercise amounted to a manual check of 2,205 locations.

The demographic population data for the years 2010, 2014 and 2018 was acquired from the NSO Malta website. The data consisted of population numbers per locality-council. Data was manually inputted in an excel spreadsheet and saved in '.csv' (comma delimited) format by the author, revised and cross checked with the data from other tables for accuracy to avoid any human error mistakes.

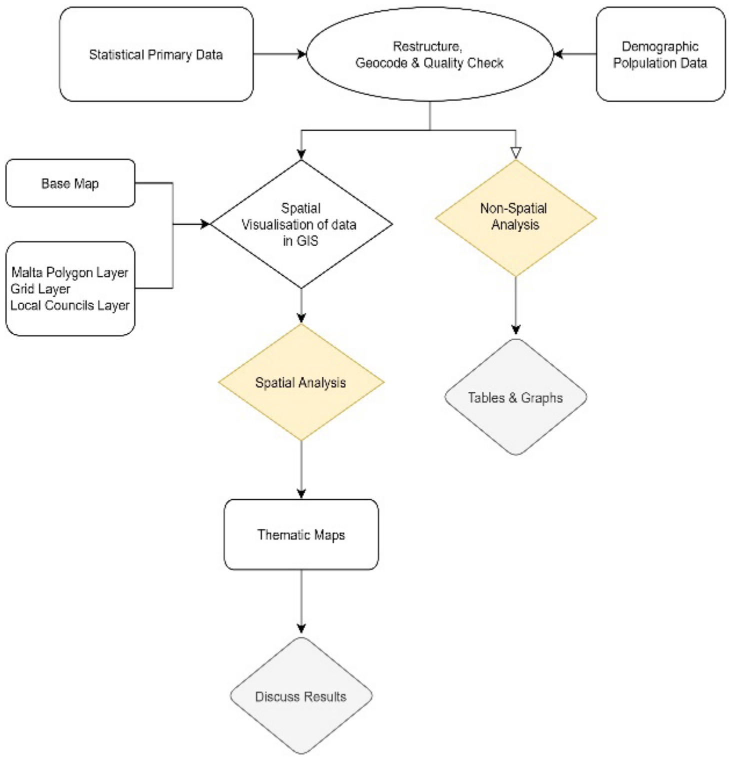
Results and Discussion

This study explored a series of experiments consisting of spatial and non-spatial analysis, at Societal and Local analytical levels, targeting to propose a potential GI methodology for crime mapping. A generic plan to serve as a guidance for these exercises is illustrated in flow chart in Figure 1.

The first one was a study of non-spatial analysis, using the statistical primary data acquired from the MPF and the demographic population data that was acquired from NSO Malta website. They consisted of various computations using the tools of the Microsoft Excel software. Following each computation, the study created respective tables and charts to facilitate and simplify the results' delivery. To visualise spatial data in a GI system and carry out spatial crime analysis, this study explored two widely established GI software; QGIS version 10.6 (Hanover) and ESRI ArcGIS Pro. Both softwares have various GI functionalities and spatial analytical tools. Nevertheless, this study identified that both QGIS and ArcGIS offer a separate specific plugin and add-on dedicated for crime spatial analysis.

A series of exercises and calculations were held related to the non-spatial analysis using the datasets gathered from MPF statistics and the data manually acquired from NSO Malta information provided in the respective website.

Figure 1: Flow Chart to serve as a guidance for the exercises



Data Analysis Results

In general, the crime of theft in Malta had a rise of 2.4% from 2010 to 2016, then the reports decreased drastically by 5.2% by 2018 and by another 4.3% by 2020. The total number of reported thefts in 2020 amounted to 4578, which is almost half of the 2016 amount. Interestingly to note that this drop commenced resulting prior, and kept its drive during the year 2020, which year experienced the origination of the worldwide Covid-19 pandemic in Malta. According to the data acquired from the National Statistics Office of Malta (NSO, updated 2021), the population has increased by 19.45% from the year 2010 to year 2019 as per Table 2.

Table 2: Population in Malta 2010 – 2019

Year	Female		Male		Total Population	
2010	208584	50.26%	206405	49.74%	414989	80.65%
2011	209851	50.26%	207695	49.74%	417546	81.15%
2012	212126	50.21%	210383	49.79%	422509	82.11%
2013	214891	50.04%	214533	49.96%	429424	83.45%
2014	219203	49.85%	220488	50.15%	439691	85.45%
2015	224019	49.74%	226396	50.26%	450415	87.53%
2016	228634	49.67%	231663	50.33%	460297	89.45%
2017	235102	49.42%	240599	50.58%	475701	92.45%
2018	241723	48.98%	251836	51.02%	493559	95.92%
2019	248802	48.35%	265762	51.65%	514564	100.00%

Spatial Analysis

Various geo-processes and spatial analysis were conducted with the data gathered by this study, to create thematic maps for the visualisation of spatial data. Spatial analyses results provided several heat maps and a variety of hotspots maps. All these thematic maps illustrated the hottest areas for all thefts in general, concentrated in the Northern Harbour region and the upper part of the Southern Harbour region of Malta. A fishnet grid of $1km^2$ intervals was created and clipped to the study area to subdivide the area of study in equal sizes, to consolidate the data and perform analysis accordingly. The kernel density estimation as per Figure 2, displays a heat map based on a calculation of the number of points, where larger number of clustered points result in larger values. The algorithm searches within a radius in map units around a point, at which the influence of other points is detected. The larger the number of detected points, the more value is given to the respective point and the greater the smoothing effect. Meanwhile, the smaller detections result in smaller values, hence the point density varied accordingly.

Figure 2: Heat map based on a calculation of the number of points

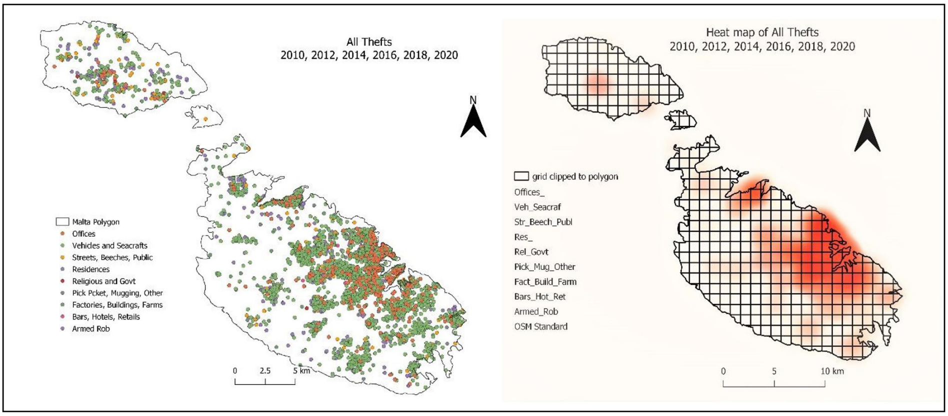
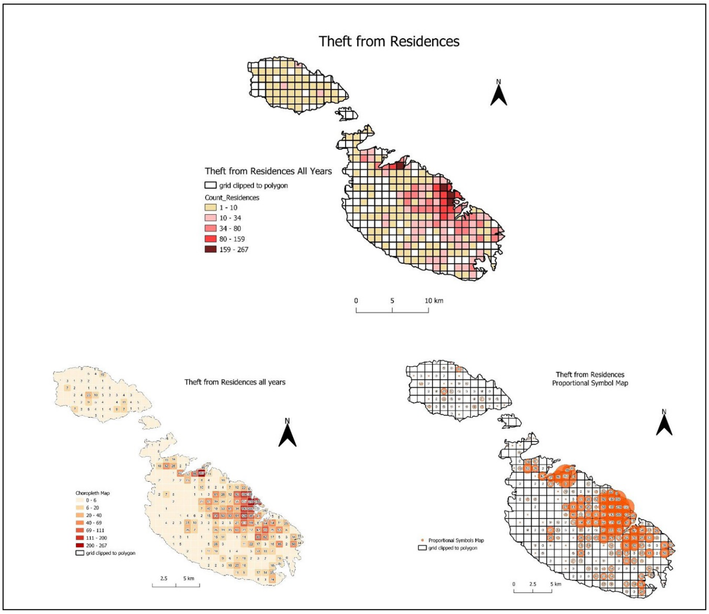


Figure 3 displays an example of thematic maps for the counts analysis where the output of the result is presented by means of a different colour in the grid boxes associated with the number of points according to respective ranges. Nevertheless, the analyst must consider and re-set the ranges of the number of points within the colour ramp display, because there might be a misinterpretation of the result. These thematic maps can display how each of the theft sub-category is dispersed through the study area, as represented with coloured grid boxes. This research selected and explored further analyses, this time using only the data of the sub-category of theft from Residences. Various visual examinations and further analysis may be conducted using these maps. These processes can include the study of crime dispersion, study of crime patterns and spatial dependency to establish spatial heterogeneity or spatial randomness. This analysis may transpire the potential reasons of why some places are targeted than others.

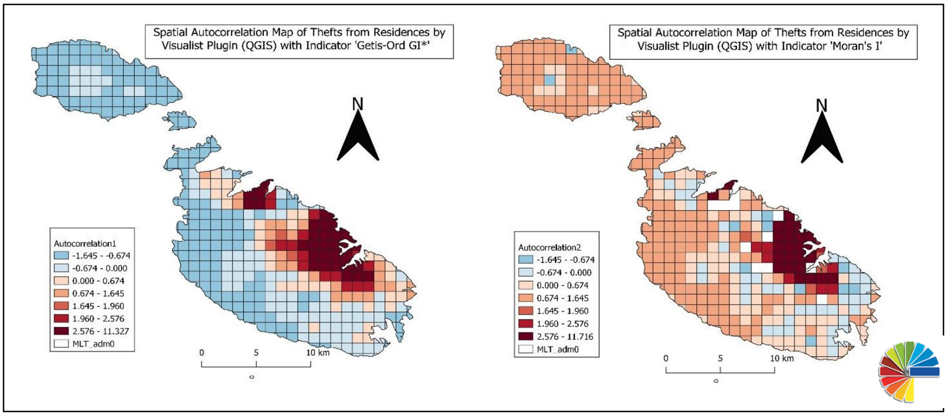
Figure 3: Thematic maps for the counts analysis



Spatial autocorrelation, also known as spatial dependency, is a spatial analysis that clusters values from points that are not independent and most likely are highly correlated. This analyses functions either with the indicator 'Getis–Ord G*' or with the indicator 'Moran's I', which maps displaying the respective results are shown in Figure 4. This study understood that the Local Moran's I is a univariate that focuses the spatial association measures on the observations of clustering in terms of a single variable. Further analysis from the results of the exercises focused on two 4-year periods, from 2010 to 2014 and from 2014 to 2018. In these two periods, there was an increase of 1% from 2010 to 2014 of reported thefts in general, while in the second period there was a decrease of 3.8% where the total of thefts in 2018 was 6528. An interesting point that is observed through non-spatial analysis in this study is that:

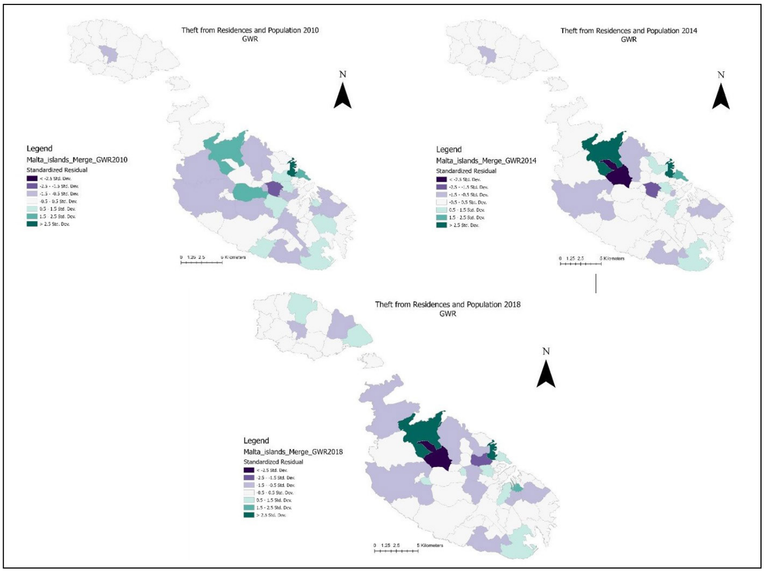
- there was a substantial increase in population 1.8% from 2010 to 2014 and by 4% from 2014 to 2018; and
- thefts increased almost by same proportion between 2010 and 2014 but then there was a change in direction of the trend, where cases dropped by 2.5% from 2014 to 2018.

Figure 4: Spatial autocorrelation analyses with the indicator 'Getis –Ord G*' and with the indicator 'Moran's I'



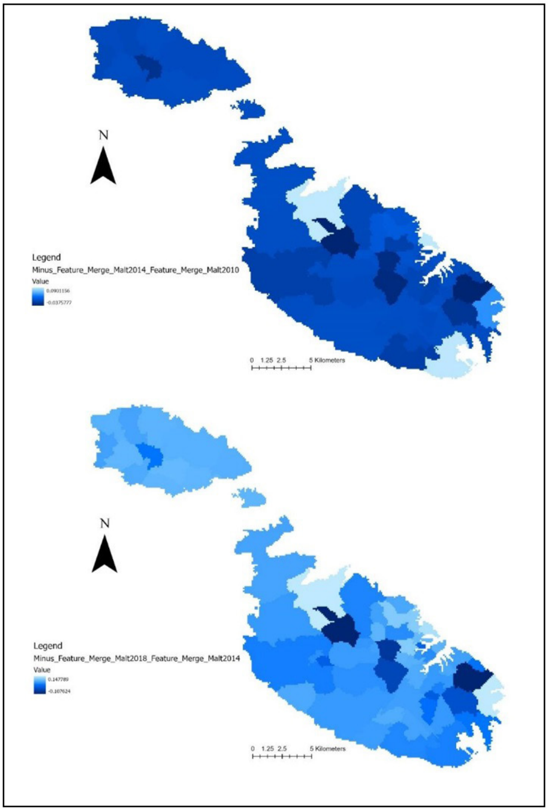
The Geographical Weighted Regression (GWR) analysis method is capable of modeling and quantifying significant non-static variation through independent variables (Fotheringham, et al., 2002). This means that parameters are estimated using a weighting function based on distance and therefore, the closer they are to the estimation point, the more the influence each location has (Cahill & Mulligaan, 2007). Figure 5 displays the GWR method estimating the influence of the population for the dependent variable of theft from Residences per local council for the years 2010, 2014 and 2018 individually. Visualising and observing the three results from the respective years, it is observed how the population change affected the number of thefts and the dispersion of the cases' numbers in certain areas, particularly on the island of Gozo in 2018.

Figure 5: GWR analyses estimating the influence of the population for the dependent variable of theft from Residences per local council



This GWR exercise led to another analysis, being a computation of a map algebraic calculation using the raster calculation 'minus' tool, to calculate the differences between the GWR map results for the years 2010 to 2014 and 2014 to 2018 (figure 6). The darker graduated colours represent a positive result and the darker it is, the bigger is the percentage of difference between the values in favour of the master raster in the calculation; being the 2014 in the first exercise and 2018 in the second. The lighter colours represent negative results; therefore, they represent graduated values in favour of the raster being subtracted. These exercises transpire that while there was an increase in values from 2010 to 2014, there was a decrease in values from 2014 to 2018. Moreover, the colour grading illustrates the spatial shifts of values from one local council to another when a comparison between the two results is performed.

Figure 6: Raster algebraic Minus calculation of GWR 2010 from GWR 2014 and Raster algebraic Minus calculation of GWR 2014 from GWR 2018



The output of this study was a geo-database model that supports object-oriented spatial data that allows relationships to be defined among features. This study recognised that the following list of tasks are widely used by law enforcement organisations in spatial crime analysis solutions using mostly crime data:

- putting contextual information digitally on to a map
- mapping the distribution of incidents
- mapping crime rate results
- conducting specific site and radial analysis
- identifying clusters from points
- identifying land use hotspot

- identifying demographics hotspot
- identifying buffer zones
- identifying comparison areas and displacements
- compute various algebraic calculations

Analysing the Covid-19 pandemic year 2020.

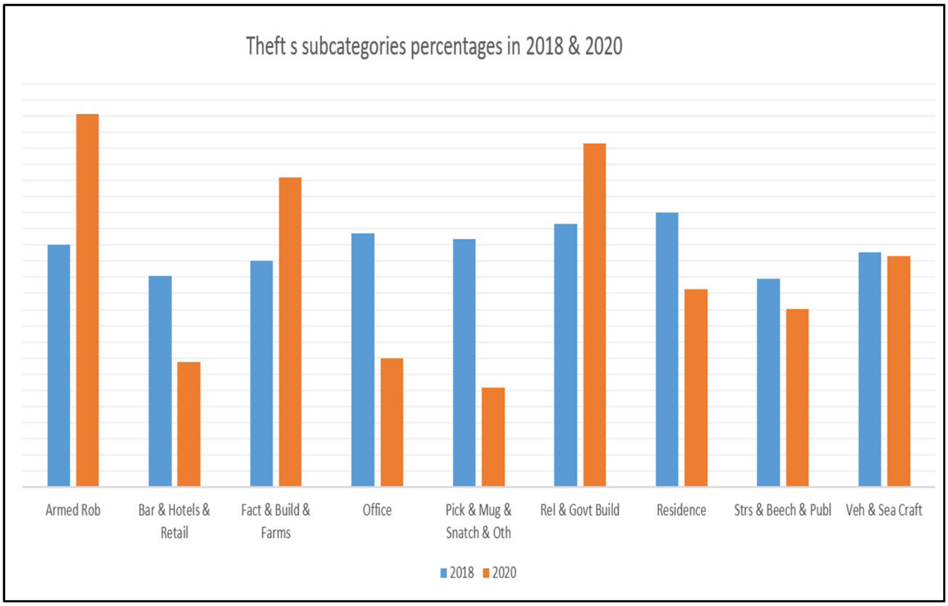
Globally, the Covid-19 pandemic brought drastic restrictions and Malta implemented various health related measures to control the spread of same pandemic, including self-isolations, quarantines, voluntary lock downs for vulnerable people, closure of various non-essential retail outlets and businesses, limitations on air travelling and movement between countries, and others. These situations led to a deviation in the execution within the theft sub-categories. As depicted in Figure 7 slight increase of 0.3% reflected on the theft from vehicles and sea crafts, but intense drops were recorded in the following theft sub-categories:

- Pick pocketing, Mugging, Snatch & Grab and others by 9.2% from 2016 in year 2018 to 823 cases in 2020;
- Theft from Offices by 7.7% from 71 in year 2018 to 36 cases in 2020;
- Theft from Bars & Restaurants, Hotels and Retail Outlets by 5.4 % from 1164 in year 2018 to 687 cases in 2020;
- Theft from Residences by 4.7% from 864 in year 2018 to 623 cases in 2020; and
- Theft from Streets, Beaches and Public Areas by 1.9% from 486 in year 2018 to 416 cases in 2020

This shift recorded a decrease in Armed Robberies by 8.1%, in Theft from Factories, Building Sites, Farms & Fields by 5.2% and in Theft from Religious and Government Buildings by 5%. However, the amounts of these percentages are relatively small numbers, being 14, 99 and 11 respectively, from a total amount of 4578 theft cases reported in 2020. From the temporal perspective, even though there was no highest point from the counts of theft in 2020 that reached the monthly count of 2018, percentage wise 2020 started the first two months with 9.5% and then dropped to 6.6% by May. This contrasts with the frequency of 2018, where in February had a percentage of 7.3% and then by May there was a rise that reached 9.7%. August kept the drive of 9.8% for 2018 to 9.7% for 2020. Both years ended almost the same percentage in the last month with only 0.1% difference.

From the spatial and temporal perspective, the crimes in general did not have a significant shift from an area to another; there were some minimal changes in the counts overall the dispersed areas, while a reduction in the hot spot areas as per figure 8. The concentration of the hot areas remained in the Northern Harbour region.

Figure 7: Thefts subcategories percentages in 2018 and 2020

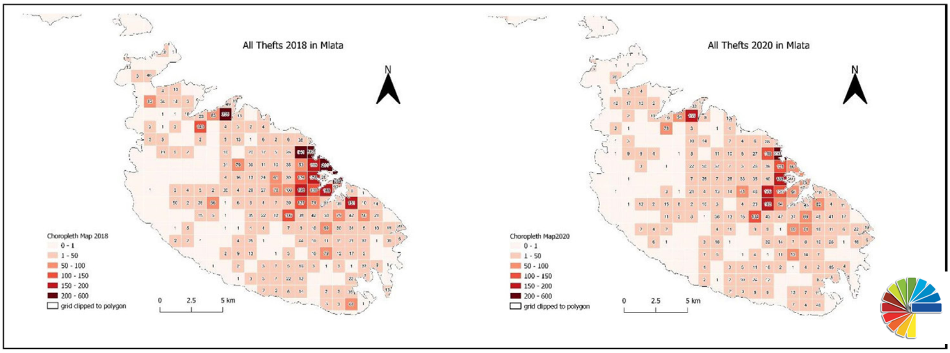


In view of this analysis, this study notes that in year 2020 of the Covid-19 pandemic:

- might have had an impact on the counts in general of the reported thefts;
- might have been the cause of a shift between the sub-categories of the theft crimes;
- caused a change in the temporal frequency; and
- had minimal to nil impact in the dispersion of crime.

Due to the reason that this particular year is considered to have an abnormal situation which affected the normal way of living worldwide, this study chose to interpret some results ad-hoc. From this study one can conclude that the scenario in Malta related to the Covid-19 pandemic rendered a local situation on the crime of theft that reflected on a shift of the target from person-based to property-based. This might also be considered as a shift from premeditated offences to more crimes held through spontaneous opportunities.

Figure 8: Theft cases counts and hotspots thematic maps for the years 2018 and 2020



Recommendations

The goal of this study was to research, analyse and explore about the development of a GIS-based crime analysis methodological framework, for the improvement of Malta's Police Force decision-making process. By exploring a series of exercises of both non-spatial and spatial analysis applying real data acquired from the MPF utilising two different software, this study managed to output results. Results from spatial crime analysis depicting heat maps and hotpots were visibly verified, cross-matched and compared with results of same thematic analysis from this study, as well as with same thematic results published by Formosa (Formosa, updated 2021) in the CrimeMalta Observatory website where it transpired that the results have significant visual similarity. This study demonstrated that to be able to work on crime data, and to better understand the spatial crime analysis results, the GIS user must be knowledgeable of certain criminological aspects. Moreover, it is crucial to have competent users: 1) as data administrators to manage the acquisition, manipulation, and quality validation of the data; and 2) as spatial crime analysts to analyse, interpret and report the data and results.

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CHAPTER 11

Investigating Browser-Based Map Accessibility for Visually Impaired Users

Karen Dimech

Keywords

Map Accessibility, GIS, Web Accessibility, Visually Impaired Users

Project Aim

The aim of this project was:

(1) to enable visually impaired users to build a comprehensive spatial understanding of a map presented via the web;

(2) establish what information a visually impaired user needs to be able to orient and familiarise themselves; and

(3) to create a sound map that can be applied to an interactive map for orientation purposes as the association of sounds to the various spatial features

Background

Web Accessibility is an ongoing issue that many developers fail to adhere to, restricting a significant number of users from accessing the full functionality of web technologies. Web Content Accessibility Guideline (WCAG) is a set of guidelines established for a wide range of web contents and functionalities, targeting several user groups with limited abilities, such as users who are visually impaired or suffer from limited muscle movement (Sloan et al., 2006). Nonetheless, complex components such as maps suffer from several accessibility shortcomings. Often, this means that embedded maps are entirely inaccessible to visually impaired users. Despite the limited research available in this field, several works are studying different techniques with the aim of making maps accessible to visually impaired users.

A significant number of online Geographical Information Systems (GIS) fall short of addressing web accessibility issues (Duffey et al., 2006). Miesenberger and Kounty (2012) elaborate on a detailed guideline for making maps and other geographical data accessible. Nowadays, we are seeing maps and geographical data being integrated into many systems and applications. Providing visual maps can be useful for various applications such as orientation and navigation services and other visual data representation purposes. However, geographical data presentation does not come without its limitations. Users who suffer from visual impairments are unable to benefit from such applications that depend on visual representations as there is no way to convey visual cues, especially in GIS, that are accessible to visually impaired users. Hence, visual data needs to be specifically adapted for users with visual impairments. Other user groups, such as deaf, elderly and cognitively disabled users also present some very particular needs that would require adapting the design of such systems to a certain degree. Visual maps should be able to communicate the same or a sufficient subset of the information to all the various needs. This can be done using other channels of perception. Nonetheless, there are no World Wide Web Consortium (W3C) guidelines in place as to what mediums/features/channels can be used to make visual maps accessible. The main reason behind this is that geographical data is closely connected to the visual sense, and therefore, it is very challenging to communicate the same level of detail conveyed through visual maps.

Web-based information and resources are more complex than plain text. Some user groups, including people with visual impairment, are being excluded from accessing all the map data and features, especially those of a more complex nature. Despite the awareness-raising efforts of the WACG standards and guidelines for conformity, the reality is that disadvantaged users are still encountering several impediments. With the correct implementation of accessible design, blind users who make use of screen readers and other assistive technologies such as screen readers, braille devices and magnifying utilities, and persons with visual impairment who need magnifying utilities and screen adjustments would be able to efficiently make use and successful access information from the web page (Brophy and Craven, 2007).

The transmission of spatial data through a sonified approach is a relatively new technique. One of the earliest map sonification projects was proposed by Krygier (1994). Krygier introduced a method to sonify visual map data through the nine sound variables: location, loudness, pitch, register, timbre, duration, rate of change, order and envelope. Krygier's sonified map inspired many others to continue in his steps and investigate this approach as a way of presenting geographical information to visually impaired users. More recent studies are using sonification on digital devices, including touch-sensitive devices such as tablets and smartphones (Schito and Fabrikant, 2018).

Earcons are non-speech audio messages used to provide information to the user through the sense of hearing to represent a computer object, operation, or interactions. Audio feedback is commonly used in Human-Computer Interaction (HCI) applications, and it is not necessarily used for visually impaired users. Earcons do not necessarily have to be realistic. However, they should capture the essence of the feature they represent.

Auditory Icons are a subset of earcons which are representational of the natural sounds that occur in real life. Sounds or Earcons can be divided into three categories: symbolic, nomic and metaphorical. Symbolic Mappings are sounds that represent social conventions for meaning; for instance, applause can represent approval among others. Nomic representations use physical sounds to show interaction, and these sounds include opening or closing a door sounds to indicate such action. Metaphoric mappings make use of sound variables to draw similarities and associations such as a continuous increasing pitch can represent a falling object (Blattner et al., 1989).

Methodology

This research was divided into three phases whereby in each phase a study was conducted. The outcomes from each phase were used to inform the study of the following phase up to the final design of the web-based map experimental tool – SonoMap. In the first phase, literature and techniques used in similar studies were reviewed. An Information Architecture technique was then used to establish an understanding of how the target user group perceives the concept of maps and mapping technologies through a card-sorting activity. The outcomes of this study were a mental model based on the participant's perceptions and insight on their personal experiences with regards to journey planning and travelling. An Information Structure was derived from these outcomes to fit the requirements of a map application based on the needs of visually impaired users. The second phase consisted of a study on sounds and sound mappings to the different spatial features.

The information used for the purpose of this study was based on the Information Structure produced from the first study. A review of the various sonification methods and sound perceptions was conducted, which was then used to design the exercise. A participatory design was held with a subset of the participants from the first phase. Information-to-sound associations were derived from this study and further insight regarding the human factors of auditory-based applications was gained. As a result of this phase, a sound map was produced. Finally, the experimental tool SonoMap was developed in the third phase using the insights from the previous phases. The tool was tested with a subset of the participants from the first study. The goals include the orientation ability based on the information provided in the map through auditory feedback and the overall usability of the tool. This study enabled one to establish whether visually impaired and blind users can construct a spatial mental model through a web-based map using sonification techniques.

The information extracted from the mental model was crucial to the design of a system. However, as stated in Pandey (2019) and Spencer and Warfel (2004), the model does not take into consideration the activities that the users follow. One of the first observations in this study is that Shops are under the category Information. However, the category of the shop (e.g. grocer, ironmongery, etc.) is more of interest than the name as this information would allow them to use other senses such as hearing or smell to guide them towards their destination. Furthermore, all the participants emphasised the importance of texture information and tactile objects within the area. The information model contains Pavement Ends Tactile Feel, which refers to the texture of the pavement and whether it is a ramp or drop at the end. This would help them know when to expect the pavement to end and be aware of cars. Moreover, for Zebra Crossings and Traffic Lights (Pelican Crossings), knowing their availability and their location would not be sufficient for visually impaired users as they would often require more information regarding the texture of the tiles of the pavement and the type of button available to activate the pelican crossing. Whereas Recreational Areas and Events are of interest for leisure purposes, participants that travel with a guide dog stated that in unfamiliar areas, they do not travel with a guide dog as they would not know whether they would have the necessary facilities such as a place for the dog. This would imply that guide dog-friendly areas should be specified on a map to offer peace of mind to the users. An ahead-of-time mapping application should be designed to allow users to travel independently. Many participants expressed that they do not feel safe travelling alone, especially to unfamiliar places and must rely on a sighted guide to orient them. A map application driven by this information would allow the users to orient themselves and feel safer when travelling to a new place.

Throughout the interviewing process, it was observed that the participants based their association of spatial features to sounds from their experience using navigation applications and other assistive technologies. As previously discussed, for visually impaired users, the concept of ahead-of time-orientation is often unclear, and maps are associated mainly for navigation purposes. An instance of this would be when asked to associate a sound to hazards, it was initially described as a high-pitched sound increasing in rhythm as the hazard approaches. Even though during map exploration, the amount of information does not allow for such techniques to be implemented in such a system, it shows that participants associate faster rhythms and higher-pitched tones with danger. Consequently, as the participants preferred the hazards to be distinguished by the imminence they pose rather than their definition, this information would be applied to the three levels of hazards. Moreover, the level of danger each hazard poses is also based on the insight from these interviews.

Visually impaired users are often trained in orientation and mobility. Therefore, the white cane allows them to identify hazards that are in their way during their travels. This implies that pavement hazards and other obstacles that can be detected using the white cane, are hazardous but do not pose a high risk to the individual as they can be detected and avoided on site. Medium level risks are those that cannot be detected with a white cane but do not put the individual in imminent danger. These risks include overhead obstacles such as trees and pregnant windows, as they cannot be detected using a white cane. However, after completing orientation and mobility training, visually impaired individuals are aware of these dangers and try to avoid areas where these risks are present. Observations on overall sound association were noted. Shorter, one-note sounds were associated with features that are not very important in the users' exploration. Features that are represented by one-note earcons also include features that are usually highlighted and prioritised in visual maps such as Hospitals and Medical Facilities.

Despite being acknowledged as important, they are considered simply as information rather than an essential feature for their journey, unless it is their destination. Melodic tunes were often mapped to features that are pivotal to their route planning such as Transport, Destination point and Pedestrian Area. The melodic sound described by participants when asked about these features always belonged to a major chord, which is indicative of cheerful tune. This reflects the attitude of users towards these features as opposed to hazards, which were described through an alarm or siren sound. It was also noted that even though in some cases, an auditory icon mimicking a real-life sound such as cars, sea and footsteps was said to be more intuitive, the sounds associated with the features were driven by the feeling of the individual when encountering the specific spatial feature. Taking into consideration the description of approaching a hazard, which is a one-note sound playing at an increasing rhythm, the sound was not simply representative of the relation to data. The increasing rhythm is highly associated with a cautionary feeling where the user should be alert.

Results and Discussion

Key results of this project are:

1. in the first phase, a consensus was not reached from the Card-Sorting exercise. However, it was noted that a pattern emerged. Despite the continuous evolution of the mental model during the card-sorting exercise, a convergence in the information could be noted. The information cards that were being added could be grouped under the same sub-category; for example, information cards like "Garbage", "Pots on Pavement" and "Poles" could all be grouped under a subcategory "Pavement Obstacles" which in a system, it would include other pavement obstacles that visually the participants did not mention;

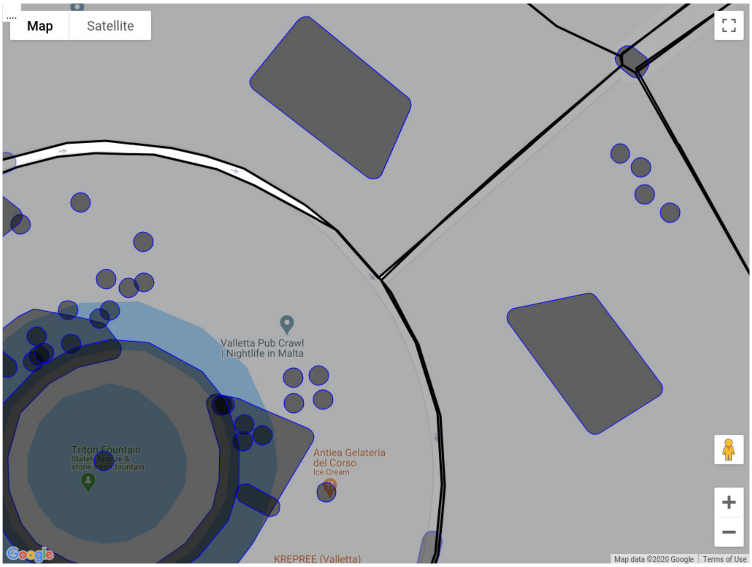
2. in the second phase, the sound map used in the final design is constructed based on information from the participatory design exercise and literature. These sound mappings are used to describe how the spatial features and map information is represented; and
3. in the third phase, an experimental tool – SonoMap, was developed using the insight from previous phases and onsite mapping of features (Figure 1). The performance of SonoMap was tested with five visually impaired and blind participants; a subset of the participants from the first phase (Figures 2 and 3). Technological background and experience with assistive technologies was not a requirement for this study. The number of spatial features encountered by the five participants was recorded for each task. For the purposes of this study, the features taken into consideration were the hazards which include obstacles, streets and construction sites, and points of interest where all the restaurants, shops and landmarks feature. Moreover, the time taken for each participant was recorded for every task.

Figure 1: Onsite mapping of features

Overall, all participants were able to orient themselves with the areas they were given in each task. From the five participants, four had visited the location at some point and were somewhat familiar with all the three scenarios to an extent. One participant had never visited the locations. From the three tasks, the second one covered an area which was least familiar to the found participants who had already visited Valletta. While exploring the map, it was observed that participants who were familiar with an area tended to look for another familiar landmark or point of interest related to it whenever they encountered a familiar landmark. Once they located a second point, they were able to orient themselves and contextualise the area that was presented to them. Furthermore, when the approximate location was established, participants would scan for a path or a pedestrian area. In areas where the participants were not so familiar with the area, a horizontal scanning system was adopted by some participants.

Figure 2: Heatmap from participant exploring map features on SonoMap

Figure 3: Spatial Features mapped on SonoMap



This method allowed the participants to explore as many features as possible to form an image of the layout of the area. The participant who had not been to the location in the case study was able to contextualise the map in all three tasks and could describe in detail how the features lay in relation to each other. Unlike the other participants, however, this participant did not feel confident to travel to that area. When the participants were asked whether they would be able to plan out a journey based on the map provided, four participants stated that given enough time, they would be able to orient themselves better. Participants that were not familiar with a map concept required more time to familiarise themselves with the area, especially to identify the scale of the map. The participants were shown the area covered by the map, while participants with previous experience (even in navigation systems) were able to determine the size of the spatial features relatively quickly. Inexperienced users found it more challenging.

Recommendations

In future research, the following aspects may be considered to enhance and compliment this study:

- Improving the information available on a map to help visually impaired users to plan their journeys ahead of time from a web-based map which is easily accessible.

- Adding features to a map application such as zooming, panning and grid overlay may improve the performance of the users and provide them with the necessary tools as complete accessible application; and
- Providing sufficient training on such a system and allowing users to get familiar with this application would give better insight on the full capabilities of ahead of time spatial contextualisation.
- There is a lack of awareness in this field of study and therefore policymakers could highlight and raise awareness on this issue. Furthermore, improving web accessibility could allow users with limited abilities to access the same information available as abled users and therefore easing the access to such development tools could allow developers to implement web-accessible content without the highly specific training.

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CHAPTER 12

The Use of Spatial Data Infrastructures and Public Participatory GIS for Crime Mapping

Omar Hili

Keywords

Participatory GIS, Crime Mapping, SDI, Spatial Data, Analysis, Spatial Databases, Spatial Services, GIS Portal

Project Aim

This project aims were to:

- provide a web-based platform where the public can log in anonymously or use their credentials to geographically report a witnessed or experienced crime, using Geographic Information Systems (GIS) tools;
- record spatial data and build a crime database with advanced spatial queries; and
- introduce the concept of Public Participatory Geographical Information Systems (PPGIS).

Introduction

Literature review focused on four main criteria, which assisted in understanding the need for an online system to report crime and the importance of such reports; to amalgamate the concept of public participation and Geographic Information Systems (GIS); to analyse what is already on the web and try better the system by understanding its User Experience (UX) and understand SDIs to reproduce a solid backend for the system to work.

The four topics reviewed are:

- The "Dark Figure of Crime"
- Public Participatory GIS (PPGIS) and Voluntary GIS
- Geographic Information Systems Portals
- Spatial Data Infrastructures (SDI)

The "Dark Figure of Crime"

The primary idea of the project was initiated by the concept of the "Dark Figure of Crime". The definition of such figures has been explained by Biderman and Riess (1967), where it was explained that the latter are occurrences that in some ways are considered a crime by law but are not registered in any way by any entity. Formosa (2007) describes the "Dark Figure of Crime" as a common phenomenon in western states where fear or disregard to the law causes the public not to report all crimes. Tolsma, Blaauw and Grotenhuis (2010) describe how the Dutch police ran information campaigns informing potential victims of the importance of reporting a crime. Through the research it was noted that the concept of empowering people to report crime anonymously is popular but in text and tabular format, allowing more difficult statistics to be collected spatially (Tolsma, Blaauw and Grotenhuis, 2010)

Public Participatory Geographic Information Systems (PPGIS) and Volunteered Geographic Information Systems (VGIS)

With the increase of popularity of a GIS-based system, PPGIS is a very much-discussed topic. Dunn (2007) mentions the need for users to be able to upload knowledge to GIS-based systems, concerning social, demographic and cultural trends. Sieber (2006) describes PPGIS as the use of GIS to expand public involvement in policy-making decisions, whilst empowering them to promote the goals of non-governmental organisations and various sectors, mainly the planning and environmental sectors. Sieber also explores the extent of GIS and technology and demonstrated the use of ICT platforms and GIS to be a valuable tool to the public.

Tang and Liu (2016) further split PPGIS into another sub-stream called VGIS. VGIS is the publishing of a portal with no data and allows the public to freely populate the spatial database within the context of the portal`s topic. A fail-safe mechanism to check and validate data is needed and in this case the proposal is to provide such mechanism to the custodians of the system.

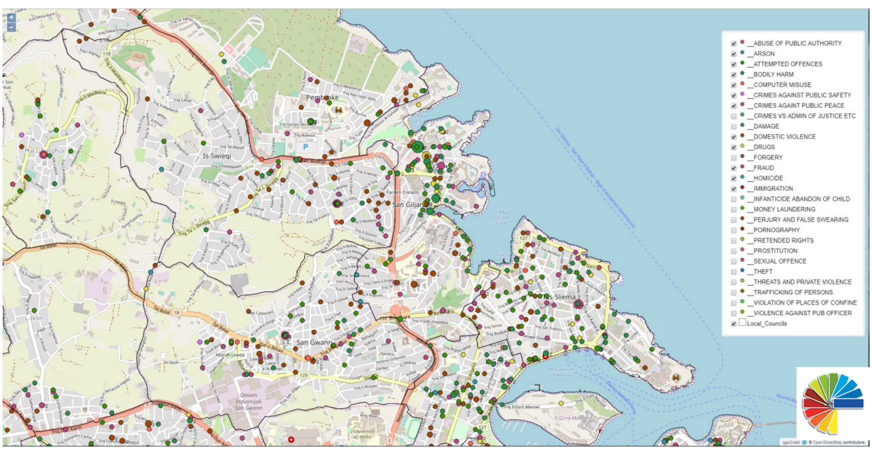
Published Crime Portals

An important criterion is to investigate current similar systems and seek to extract their functionalities to better integrate them into the proposed project. Some of the sites offer minimal to no interaction with the public, only showing data which has been manually entered. Others offer more complex querying tools but display an overall cluttered page which might confuse with the public domain.

Formosa (2018) showcases the use of a GIS portal (www.crimemalta.com) to display his findings (Figure 1). The website and portal are mainly informative, as they provide visual information or data that has been acquired through different means. The portal provides crime categories which are categorised by the local council and provide graduated symbology to display the amount of selected crime within a specific council. The site offers the possibility to view graduated and heatmaps but is not integrated into the current web view. Users need to revert to the main page and choose a different URL to visualise a HeatMap in a new tab. As per Figure 6, heatmaps are a graduated symbol which extends according to the value concentrated in a geographic area. Where color intensity and radius size are large, this denotes a high concentration of crime. The heatmaps provide direct interpretations of values just by viewing the map. Liu, Jian and Lu (2010) demonstrate a different portal, where with the use of GIS, the developer has provided a query and spatial search engine to identify crime patterns in Washington DC. In this portal analysis, one can immediately figure out the complex usability of the portal.

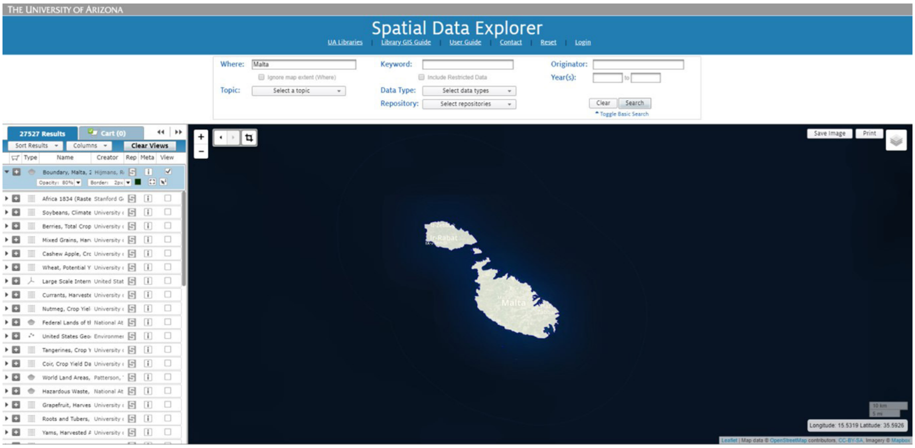
An interactive design and functionality matrix were observed in the portal proposed by the University of Arizona (2019). Figure 2 demonstrates the visual representation of the viewer with the top section displaying the query tools, including advanced query tools and filtering, whilst the left-hand side displays the layers that are available to view.

Figure 1: Graduated symbology according to the total crime for the selected category



Source: Formosa, 2018,
https://www.crimemalta.com/QGIS/geopol2018_maincateg_cluster/geopol2018_maincateg.html

Figure 2: Spatial Data Explorer



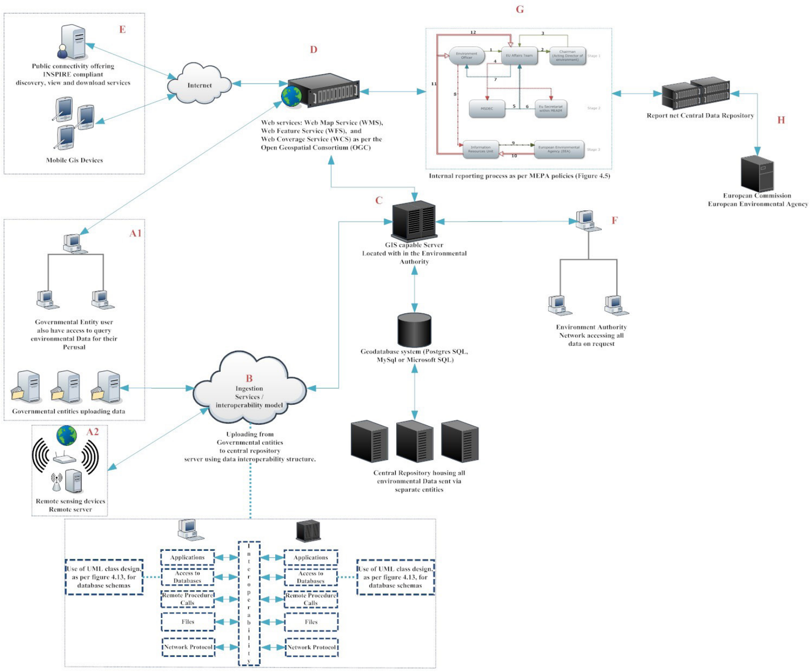
Source University of Arizona, 2019

Spatial Data Infrastructures

The term National Spatial Data Infrastructure (NSDI) was introduced in 1993 (FGDC, 1993) as an initiative to provide standardised access to Geographic information resources. It consists of a framework which highlights technologies, institutional arrangements and policies which work in harmony to facilitate and standardise the creation and exchange of geospatial data (ESRI, 2010). The main aim of SDIs is to facilitate access and search of spatial data to non-profit organisations, governmental bodies, private entities and the general public (GSDI, 2004).

The core concept of the SDI is to use Information Communication Technologies (ICT) to provide a structure to host and disseminate spatial data in various ways such as geodatabases, flat file data sharing and the most widely used, standardised web-based services. The services can be consumed by various applications ranging from mobile devices applications to common browsers on desktops. An example of geospatial web service consumption is presented by Hili (2014), in the presentation of a conceptual model for an environmental SDI in Malta (Figure 3). This proposed model displays the flow from the backend systems, such as servers and databases, to remote sensing devices with ingestion services, which then lead to the dissemination services including the INSPIRE compliance process. The Maltese Government has also embarked on a project called SIntegraM (2012) which aims to develop an SDI for the Maltese Islands.

Figure 3: A Conceptual Model for geospatial services



Source Hili, 2014

Whilst researching the topic on crime abuse on users, it was noted that human beings can suffer abuse and have limited ways of reporting. This occurs due to fear, intimidation or lack of willingness. Formosa (2007) indicates that less than 50% of violent crimes are reported thus promoting the need to provide tools to the public to report. Such a proposed system may in the future allow the user to move a step forward and report a crime even in an anonymous way allowing users to feel safe whilst reporting the illegalities.

Methodology

The methodology adopted was a Qualitative Mixed Method Research (MMR) (Archibalt et al. 2015). This approach comprised surveys, interviews, secondary data analysis and participants' observations, and has proven valuable for this project. The primary task was to first understand the concept of spatial data and crime reporting tools. The primary investigation was based on understanding similar systems to understand user needs and trends. Further investigation on topics such as the "Dark Figure of Crime

(Talyor, 2013), PPGIS and Voluntary GIS, GIS portals and Spatial Data Infrastructures provided the knowledge to construct the Spatial Portal.

The second research conducted was via interviews and online questionnaires, where the user requirements were extracted and recorded including the functional requirements of the system. The interviews were conducted with two key experts from different fields - local criminology expert Prof. Saviour Formosa and GIS ICT expert Mr. Brian Borg. The aim of the interviews was to gather more in-depth information on the two topics to provide a system that was constructed not only based on desk-based research but also on actual real-life scenarios. Both interviewees have significant experience in their respective fields and were a key source of information. Due to time limitations in the study, direct interviews with the local police authorities were not possible. The project research and completion had to be finalised in a span of 20 weeks thus allowing only 2 weeks for interviews, data collection and analysis.

The questionnaire's main aim was to understand the willingness of the public to use such systems and confirm that by providing anonymity there will be an increase in the use of such a portal. The questionnaire was published using an online tool and ensured that no personal details were requested. The anonymity on the questionnaire was to ensure that the users were objective in their replies without issues on any repercussions.

The backend and frontend were also designed after researching various models and Spatial Data Infrastructures. The backend solution is the infrastructure used to save the geospatial data and the publishing of services, this is the invisible data layer to the public and service consumers. The front-end system is the designed solution where all functionality, such as map, search and data input are displayed via a web page. The front end is the graphical interface which the user browses to make use of the spatial information on the web site. The second investigation was on the backend server technologies available to collect the spatial data and allow on-the-fly queries. Subsequently, the installation and publishing of the backend service to communicate with the frontend, the testing phase was initiated. Having a fully functional prototype allowed the user to start working on the system where the developer could then identify any IT bugs and adjust accordingly.

Results

The process adopted was to finalise both the backend solution with integration to the front-end portal in order to start preliminary testing. The testing was divided into two sections, the backend testing and front-end portal functionalities tied to the backend.

The backend testing performed is based on three main factors:

- Loading of services and their response time;
- Consumption of such services via third party applications (QGIS); and
- Plotting/querying data from other sources.

All the performed tests were successful thus allowing to continue testing the front-end solution with replies on the backend solution to function using test data.

The frontend portal testing was conducted by selecting focus groups and including one-to-one meetings with candidates who showed interest in a test trial through the online questionnaire. A total of ten participants were enrolled in the testing phase and were divided into two focus groups of five persons and a one-to-one session with the remaining five. Two different data gathering options were used to try and collate as much data as possible. The questions in the focus groups were pre-defined to gather data which would allow the design, implementation and usability of the systems. Targeted questions were also provided to gather knowledge of the backend system functionality and help provide more query tools. The one-to-one interviews were more open ended allowing the user to express their opinion on the systems thus also allowing to eliminate or add functionalities which were not high-lighted in the focus groups.

Each participant was provided a use case matrix of all the present functionalities. The users were requested to check whether the function was working properly or if there were any issues, they were to provide details or comments. The matrix functionality included functions such as, address search, zoom, home button including more advanced features such a toggle heatmaps, field selections and switching of basemaps to orthoimagery, both functions are standard functions in the ESRI free API. The findings of the interviews were recorded, and the recorded bugs were addressed. Some of the bugs fixed were the adjustment of feature service visibility to be able to use map service in the Table of Contents. Detailed spatial data information on screen and the mobile responsiveness was adjusted. Users highlighted the need of a display container below the CrimeTag tools to indicate the results achieved from queries. The second suggestion received was to include a quick help manual to help using the site. Both suggestions were implemented.

The overall testing phase was concluded with no major changes to the code. This was a crucial part because if large changes were needed some parts of the code would have required re-writing and this would have shifted the project deadline. Issues such as the location button, and signed certificates were not catered for during the implementation but were highlighted during testing. Functionalities such as the transparent feature service were also recorded and adjusted during the testing phase, thus the issue can be catered for.

The results aimed to construct a full system that allows generic users and local enforcement agencies to record crimes in a spatial way using ICT and GIS technologies.

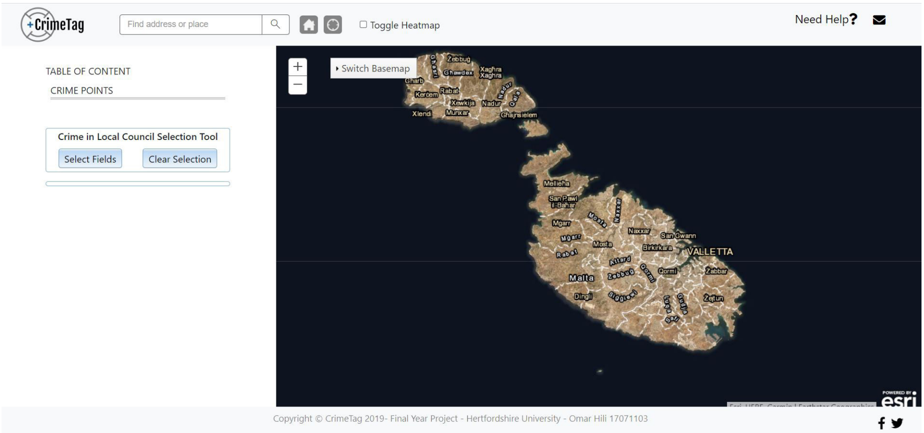
The key results to be obtained are:

1. design a front-end portal for user functionalities;
2. implement Front end design to provide a functional product;
3. design a backend system including spatial databases and spatial service;
4. publish online Geospatial service;
5. implement communication between Front-end portal and Backend systems; and
6. provide online reporting and geospatial analysis tools using both front and back-end services

Discussion

The primary output for the project was the completion of a functional Geoportal for the plotting of crime within a geospatial context including public web services. The overall objective was achieved and as Figure 4 demonstrates, the portal was published in a test environment and populated with test data. The portal also promoted on-the-fly analysis like querying of data, heat maps together with data inputting with the possibility of overlaying orthoimagery together with the data. Figure 6 shows a heatmap displaying areas of crime by colour intensity. As previously discussed, the heatmap provided a quick visual overview of potential problematic areas where crime may be more common. The use of this map is to give an immediate overview of the whole islands and identify potential additional law enforcement. Figure 7 displays the category filtering including the spatial attribute information. The addition of a basemap selection was also added to provide a reference with the possibility to overlay aerial ortho imagery so as to better understand the surroundings of the filtered data.

Figure 5: Final Published Geoportal



Source Hili, 2014

Figure 6: Choropleth map displaying areas of crime by colour intensity

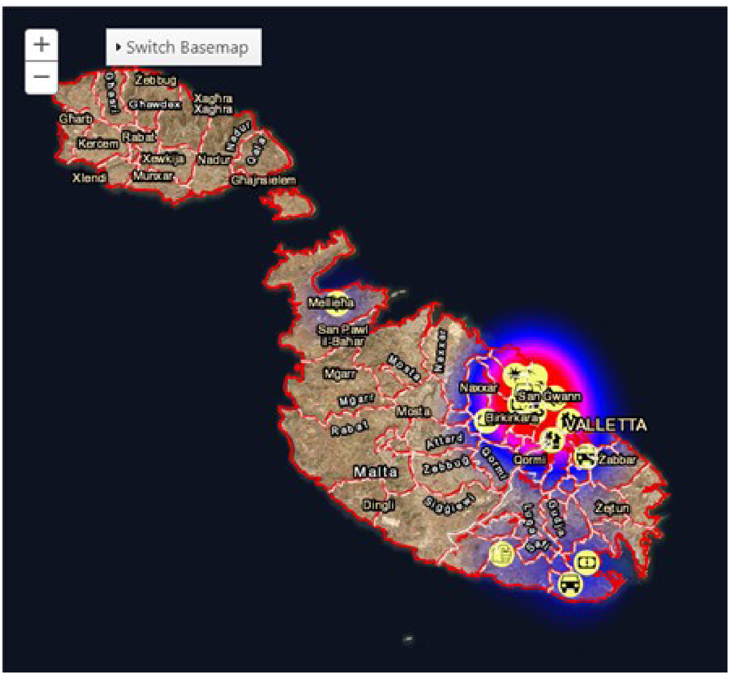
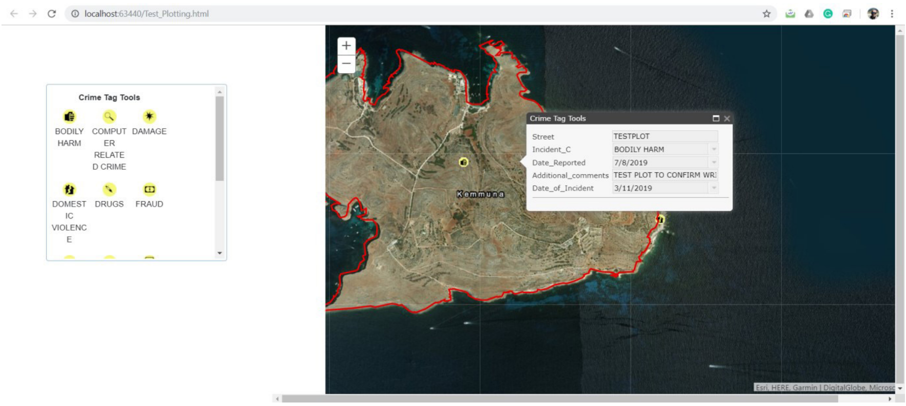


Figure 7: Test plot in the middle of Comino to confirm registered plot

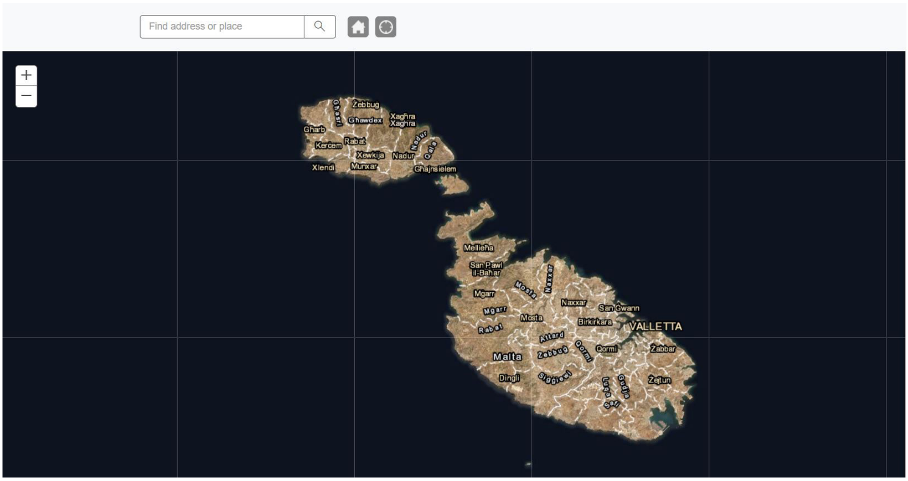


The second set of spatial results was to produce a functional public geospatial service where the data could be accessed using different platforms and spatial software. The data was published via an ESRI server and providing map services for graphical representation of data, the feature service for adding geometric data and populating database, the Keyhole Markup Language (KML) service to cross publish to Google maps and Web Map Services (WMS) to enable sharing of data in a view only method. Results were successful even when ingesting the services in Geospatial software such as QGIS.

The third output was to provide on-the-fly spatial analysis tools where once the data was collected and displayed on the portal, the user could also query and produce visual support to understand the actual data. For the spatial tools the Content filtering (side panel for the visual selection of data) was used to spatially display only selected categories of crime thus filtering the selection.

The localisation function, which was primarily intended for mobile devices because of accuracy, was also implemented pinpointing the approximate (depending on device used) location of the device recording the crime. This result varied when using desktop computers since geo-location is calculated on the home/office IP. Another spatial tool implemented was the street search where, if a user observed a crime but did not have a device where to record the instance, one could search the street where the crime occurred and record the necessary details. Figure 8 shows the results of this functionality. The result was to produce an on-the-fly heatmap analysis where graphically, the user could understand crime occurrences over the island. Overall results were achieved with all systems being functional and providing the spatial recording and querying of data in various forms.

Figure 8: Localisation and street search functionalities



Recommendations

The research was focused on three main criteria:

1. Understand ICT and GIS technologies to build an SDIs;
2. Introduce the concept of PPGIS and VGIS; and
3. Produce an online portal with tools to empower the user to report crime anonymously

The system is based on an IIS web portal, where a recommendation for major future improvement would be to create a mobile application that can read the current web service to allow the users to report a crime from anywhere using mobile devices. Future improvements would be to increase spatial queries and assist various other private and governmental entities to create their own tailored queries, which results could also be made downloadable.

The second recommendation would be to clearly identify the potential use of the system to the police forces but also assess the repercussions of publishing the data to the general public. If misused the erroneous inputting of data in a particular area might demark it as "not safe" thus putting police efforts in areas not particularly dangerous or even depreciate property value of the said area. A possible solution to this is for the users reporting a crime to pass through their e-ID (Malta Government Electronic Identification System) and inform the local authorities accordingly and minimise abuse. Using the e-ID might also pose a limitation to people who want to remain unidentified. Over-complicating the report process might also hinder the amount of data received so one needs to evaluate and simplify the reporting process keeping a balance with quality data.

Further studies would be the integration of multiple GIS web services on a unified portal to provide cross analysis of GIS data. One could propose a national spatial repository for governmental entities or academia where various analyses on different topics can be discussed. Topics such as population migration compared to crime areas, property prices and ease of travel to work would be interesting to investigate.

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CHAPTER 13

The measurement of crime in Malta: a geographic analysis

Shawn Pawney

Keywords

Crime prevalence, crime severity, GIS, Crime

Project Aim

The aims of this study were to:

- provide a quantitative measure for what is essentially a qualitative issue: crime severity. This index would then aim to compare permille crime prevalence information to illustrate key differences between the two methods for the 2016-2021 period.
- To analyse the geographic differences that emerge in the 2016-2021 period on the local scale.

Introduction

Sherman et al. (2016, p.171) summarise the issue of crime measurement:

"A count of all crimes has no specific meaning unless all crimes are created equal. All crimes are not created equal. Counting them as if they are, fosters distortion of risk assessments, resource allocation, and accountability. Integrating all crimes in a weighted index represents a far more useful approach for resource allocation and crime prevention"

The aim of study was to provide a platform upon which law enforcement in Malta (mainly the Malta Police Force) can have a better understanding of which are the changing patterns in crime distribution in the Maltese islands. The study also aimed at giving recommendations on how to improve data collection and sourcing to provide further improvements to such a platform. For this study crimes were scored according to a sentencing-based score currently being used in the United Kingdom to assist law enforcement agencies (ONS 2022; 2022a; 2022b), the score being very similar in principle to the Cambridge Crime Index (Sherman et al., 2017). This methodology is often referred to as a sentencing-based weighing approach, which is essentially a weight based on either sentencing guidelines, average sentences, or minimum sentencing. The weighting in this case is based on average days in prison (or equivalent) in the UK legal system.

This study is part of a wider unpublished study conducted by the author (Pawney 2022) which has been adapted to reflect a single geographic scale (the local), as opposed to the multiple scale of the original study.

Literature Review

Measuring Severity

Sellin and Wolfgang (1964) attempted to address the measurement of crime severity, an essentially qualitative issue, using quantitative approaches, in a seminal piece of literature pertaining to the indexing of crime severity. Blumstein (1974), Roach (1967) and Rose (1966) expressed reservations towards the methodology of Sellin and Wolfgang's (1964) study, while Akman, et al. (1967), Silvey (1961) and Welford and Wiatrowski (1975) defended the work and provided their own cases studies and replication in different territories. In a study in Baltimore, Rossi, et al. (1974) also found relative agreement relating to crime seriousness, especially regarding more grievous offences.

Levi & Jones (1985) reviewed the use of seriousness indexes based on police data from two localities in the Northern and Southern regions of England, once again highlighting the relative convergence between attitudes of the public and law. Levi & Jones' (1985) study was also replicated by Corbett & Simon (1991), this time centred around the seriousness of traffic infractions. Kwan et al. (2000) also explored the idea that crime severity can be considered not as an objective variable weighted by the maximum penalty that could be inflicted for a particular crime, but instead espouse the notion of adopting a mixed subjective perspective. Ip et al. (2007) also provide a similar study based on the Thurstone (1928) method but made some adjustments, leading to an index that provides a hierarchical structure. The authors argue that this aims to reduce the workload related to data collection. The authors then compare the results of the hierarchical and non-hierarchical methodologies. Formosa (2007) provides the first review of crime on a spatial, and temporal scale while also providing a profile of the typical local offender. The study in 2007 illustrated changes in crime rates related to the transitional population, together with the increase in incarceration rate amongst foreign residents. The Harbour regions were also highlighted as crime hotspots.

The Sentencing Approach

The crime severity index introduced in 2009 by Wallace et al. (2009) designed a methodology through a joint effort between local enforcement, provincial, and territorial authorities, and with the collaboration of academics, providing an index that considers both the objective and subjective views of crime seriousness. This, according to the authors, is done by using an index based on sentencing rather than the maximum penalty applicable. This provided a hybrid methodology through which crime can be weighted.

In a study exploring a more democratic form of policing and decision-making, Sherman (2013) suggested the introduction of a weighted crime measurement system. In 2016, Sherman et. al published their framework on how to create a weighted crime index based on minimum sentencing guidelines. During the same period, the Office for National Statistics in the United Kingdom (2022a; 2022b; 2022c) also published a weighted tool for measuring crime. It was first published as an experimental tool, followed by the implementation of periodic updates. The tool is very similar to the Cambridge Harm Index, but is based on average actual sentencing, rather than minimum sentencing guidelines. Ashby (2018) illustrates the similarities and advantages of both the Cambridge Harm Index and the Crime Severity index and explained that these produced rather different results. Therefore, more studies would be needed to consolidate these methodologies. Sherman (2020) stresses the importance of weighted indices as opposed to traditional methods, which treat all crimes as being equal.

Various studies have been published replicating similar methodologies, including House and Neyroud (2018), who published a Crime Harm Index (CHI) for Western Australia, Andersen and Mueller-Johnson (2018) published a similar index for Denmark. Kärrholm et al. (2020) also published a similar index for Sweden. Mitchell (2017) provides an index for the city of Sacramento, in the state of California (United States), Weir (2019), Frydensberg et al. (2019), Bland (2019), and Fenimore (2019) provide examples in which crime harm data can be used for crime reduction and prevention purposes.

Methodology

The first measure of crime is incidence, which describes a definite amount of crime within a definite period. This variable does not account for population, area, or any other information other than the raw number of crimes in a definite location and time. The second measure discussed is crime prevalence, which is the incidence of crime in a definite area, in a definite time, in proportion to a definite population. The results are usually expressed in crimes per thousand inhabitants. In this case permanent population has been used,

$$Crime\ Prevalence\ (CPK) = \ Crime\ Incidence\ \times\ \frac{1000}{Yearly\ Population}$$

The measure of crime illustrated in the Office for National Statistics (UK) (2022a, 2022b) and which sets scores based on actual sentencing expressed as days in incarceration or equivalent (In case of non-custodial punishments), can provide the weighted severity for one particular crime which can be simply expressed as:

$$Crime\ severity\ index\ (CSI) = Crime\ Incidence \times \frac{severity\ score}{Yearly\ Population}$$

This expression provides the score for each crime needed to be summed up for a definite geographic area, depending on the geographic scale. The calculation of the CPK and CSI weights used by the Office of National Statistics UK (2022a, 2022b) were adapted for this study, using specific scores in the tool according to the crime. The basis upon which scores are given is based on actual sentencing and each point represents a day in prison equivalent. While an-ad hoc weighting could be created for the Maltese islands, this would entail a study on its own.

All population data was acquired from data provided by the Malta National Statistics Office (NSO 2011, 2022), while raw crime data was acquired by the author by a request for information of categorised data for all crimes reported between 2016 and 2022 to the Malta Police Force. Local boundaries and a base map have been procured from the Malta Planning Authority portal (PA, 2022). The data represents all the reports filed in the systems and despite various possible limitations related to the dark figure of crime and to data collection, categorisation, and generalisation, this data is the most complete data set identified. All map categories have been used using a six-year national average as the benchmark for the categories, which were then set into quantiles.

Results

Figure 1 illustrates crime prevalence per 1000 inhabitants in Maltese localities in 2016. Of the years under study, this year is the one with the highest number of crimes (Figure 7) reported despite it being the year with the lowest recorded population. When analysing the general crime from 2016 to 2021, one can notice a declining trend in both crime incidence and prevalence, with a trough in crime data appearing in 2020, the year of the COVID-19 pandemic. From data available crime incidence in 2021 was at the same level as it was in the year 2019. These numbers provide one dimension of reality. This study showed that a geographic and holistic analysis can provide further information and help understand how the raw data has changed during time.

Figure 1: Crime Prevalence for Malta Localities 2016. Crime indicated by locality per 1000 inhabitants

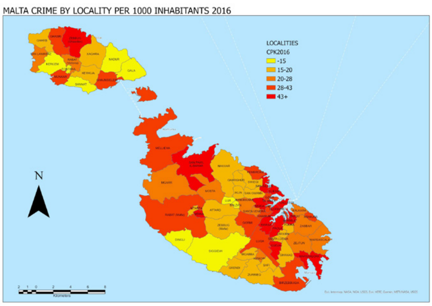


Figure 2: Crime Prevalence for Malta Localities 2021. Crime indicated by locality per 1000 inhabitants

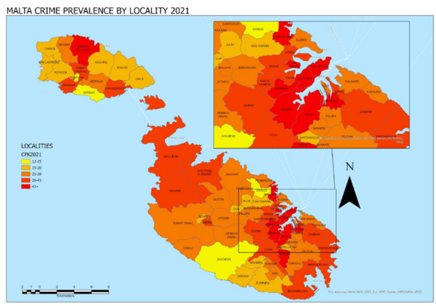


Figure 1 shows that by 2016 most crime was concentrated in harbour localities and localities which are influenced by high levels of transitional population. The crime pattern is very similar to what illustrated by Formosa (2007), with localities exposed to tourists and commuters (examples: Valletta, St. Julians, St. Paul's Bay, Floriana, Sliema) presenting very high crime and crime prevalence figures. On the other hand, this pattern, as seen from the data presented is in constant evolution, and while these areas still present above-average figures, it is very clear that a change has occurred in the last fifteen years, and that the COVID pandemic appears to have had further evidenced this change.

Of particular importance are the localities of Valletta (162 CPK), Mdina (187 CPK), Sliema (73 CPK), Marsaxlokk (60 CPK), Saint Paul's Bay (65 CPK) Gudja (59 CPK, which includes the Malta International Airport) and Saint Julian's (206 CPK) which exhibit a very high level of crime prevalence compared to the Maltese average of 37 crimes per 1000 inhabitants (CPK). In 2016 Sliema, Mdina, Valletta, and St. Julian's were the target of substantial pickpocketing activity, which factor has, without a doubt influenced not only the local incidence and prevalence rates but has also had a substantial effect on the national scale. Apart from this phenomenon, one can also note a pattern of crime being most concentrated in the harbour and airport regions, with Floriana also appearing to have an unusually high level of prevalence (154 CPK). This is probably related to the fact that many reports are filed in the Police GHQ located in that town. In Gozo, Żebbuġ and Għajnsielem present the same issue of being tourist-rich areas, while Munxar appears to be the only locality with a high crime prevalence without an apparent reason. Most other Gozitan localities have rates below the national average.

Figure 2 illustrates the crime prevalence rates in 2021. The scenario presented by this map is very different. Through these years the effects of pickpocketing and most other theft categories in most localities have fallen drastically and the emergence of domestic crimes, fraud, amongst other offences have changed the geographic distribution of crimes through space. This was of course a shift which can be seen through the years but 2021 marks the pinnacle of this shift. In fact, despite levels of crime going back to the 2019 levels, the aforementioned crimes have continued in their downward trend, while crimes such as fraud, money laundering, and domestic violence have been on the increase, possibly driven by an increase in information and awareness.

In 2021, while Harbour areas are still the main hotspots of crime it is apparent that redistribution of crime has been occurring. In Figure 5 one can see changes occurring in this timeframe and space. In Figure 5 it is evident how most coastal and areas prone to transitional populations have seen remarkable drops in crime prevalence, Valletta (-52 CPK). Saint Julian's (-94 CPK). Sliema (-28 CPK), Mdina (-147 CPK), Floriana (-66 CPK) has all experienced decreases of 20 to 50 per cent in crime prevalence rates. On the other hand, while not so substantial, most localities in the hinterland and in Gozo, which has been having an upward trend in crime incidence and prevalence. have experienced increases, in some cases exceeding the 25 per cent mark. This phenomenon might be related to new reporting patterns, and in the cases of localities such as Gozo and Mgarr, to increases in transitional populations represented by tourists, Maltese holidaymakers and beachgoers.

Figure 3 illustrates a similar picture to that in Figure 1, but it also has remarkable differences. Most low crime in this map feature in the first quartile which is marked by very high indices in the harbour localities. This is probably due to the very high levels of pickpocketing and theft-related crimes which have a substantial crime score. Many areas in the hinterland would feature less "high-level" crime and therefore these have very low scores. The average Crime Severity Index for Malta in 2016 was calculated to be 4.85, while localities such as Valletta (19), Saint Julian's (25), Mdina (16), Marsa (10), Floriana (19), Saint Paul's Bay (9). And Sliema (8), featured vastly higher scores. With regards to Gozo, Munxar presents an interesting example, as it showed a higher-than-average crime prevalence index in Figure 1, while in terms of crime severity (3.2) the score is well below the average. This is the case with various other localities around the Maltese Islands as can be seen when comparing Figure 1 and 3.

Figure 4 illustrates the Crime Severity Index calculated for localities in 2021. It is apparent when one compares this map to Figure 2 that, while Gozo for instance has seen increases in crime prevalence, in most localities on the island, this did not translate into an increase in the CSI. This is most probably related to the fact that most increases were of relatively low scoring crimes and therefore the effect on the severity index was contained. In many localities on the main island this is also the case.

Figure 3: Crime Severity Index for Malta Localities 2016. Crime is indicated by locality as weighted crime score per 1000 inhabitants

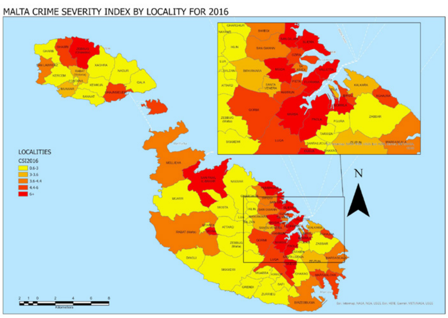


Figure 4: Crime Severity Index for Malta Localities 2021. Crime is indicated by locality as weighted crime score per 1000 inhabitants

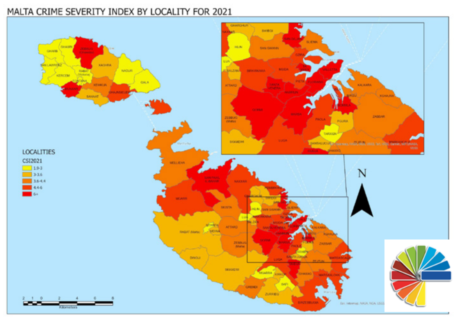


Figure 6 illustrates changes in the CSI between 2016 to 2021. Marked decreases can be seen in localities such as: Valletta (-9), Mdina (-13) and Saint Julian's (-14). On the other hand, localities such as Marsa (+8) have had the largest increase in the time period. The most remarkable indication that results from both Figure 5 and 6 was perhaps the fact that not only most localities in the hinterland have experienced increases in crime prevalence, but that the data suggests that this increase is having a more adverse effect on the crime severity index, meaning that the index is influenced by higher scoring crimes. In fact, most of the localities that experienced increases in the CSI are seen to have experienced increases over 25%, and in many cases, especially in Gozo of over 50%. This illustration gives further depth to what was illustrated in Figure 4, and while many localities appear to have had no dramatic increases in the crime severity scores, these scores and crime prevalence are surely on the increase. As stated before, this is most likely influenced by various factors including the changing paradigm of crime, and crime reporting. The changing paradigm is further evidenced when the geographic analysis is compared to what was illustrated in Formosa (2007), since from the time of the study it is even more apparent how crime patterns have been shifting from the harbour regions to the inland towns and Gozo.

Figure 5: Crime Prevalence map for Malta Localities change between 2021 and 2016. Crime indicated by locality per 1000 inhabitants

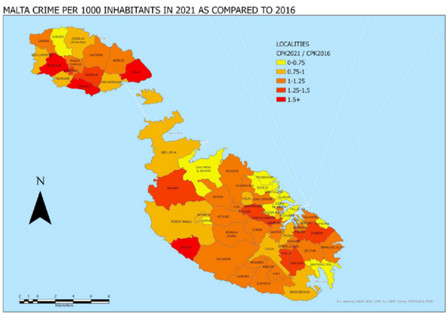
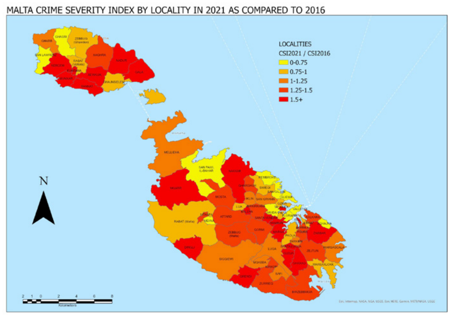


Figure 6: Crime Severity Index for Malta Localities change between 2021 and 2016 Crime is indicated by locality as weighted crime score per 1000 inhabitants



Discussion

The illustrations presented in this article are in the locality scale and form part of the data and work conducted on different scales (Pawney 2022). This study focused on two years of reference and one geographical scale, the locality scale. By analysing outputs from these illustrations, the data as a whole, and what emerged from the study from the national, regional, but also microscale of particular localities, the advantages of having different methods of measuring crime were noted, as weighted scores provided further depth to the data. Incidence data is useful when one wants to compare individual units separately. National Statistics data are a case in point. Prevalence helps us to understand trends when comparing one unit to others: a case in point would be Eurostat Data which publishes data of countries having different population sizes. In that case, it would surely make no sense to publish incidence data. Crime Severity Indices can provide more understanding to policymakers. Crime Severity indices may be best perhaps seen as the median, while a prevalence index would serve as a mean or average.

This study showed how prevalence markers, while useful, fail to show a very important feature, in that not all crimes are the same. In prevalence, each crime has an equal score usually set to 1, while the Crime Severity Index (ONS 2022b) provides a score based on actual sentencing, expressed in days in prison or equivalent. To provide an example of scores within this index, a case of wilful homicide scores 7,832 (equivalent to 21.4 years), Rape scores at 3,285 points (9 years equivalent), Burglary scores 564 points (1.5 years equivalent), while criminal damage score 9 points (9 days equivalent). These figures compare well to average sentencing in Malta. What emerged more clearly from this analysis is that while nationally socioeconomic changes are occurring, crime patterns are also changing, showing a shift towards the hinterland. It is also apparent that the smaller the scale is, the more volatile both indices can become, and therefore both crime prevalence and severity indices are probably best used on the regional and administrative scale (in the case of crime on the Police Region scale) when used for administrative decisions.

Another point of discussion is the transitional population related to local and foreign tourists, commuters, and particular aspects of localities. As seen localities such as Valletta, Saint Julian's, Sliema, Żebbuġ (Gozo, includes Marsalforn), Għajnsielem (inclusive of Comino) and Mdina were heavily characterised by seasonal crimes such as pick-pocketing which effectively target persons who are not residents in that geographic location but still will influence local statistics. Floriana can perhaps be described as an outlier, as it is probably the location in which many reports are taken, but not necessarily the location where these offences occurred. The same can be said about Gudja, which includes the Malta Airport, various reports in this locality would have occurred abroad but would have been listed as the locality of the report.

Recommendations

Key recommendations emanating from this study:

- To address anomalies in the reporting system as explained in the cases of Gudja and Floriana and have a more accurate geographic representation of reports which are taken out of geographic context. Reporting could be further segmented to indicate offences and crime aggravating factors (Currently there is no indication if theft is aggravated by value, means or any other element except for violence) so that crimes reported are indicative of articles of the law;
- To have ad hoc crime severity scores based on Maltese Jurisprudence and sentencing guidelines to have a more Malta-specific score. This would require an *ad hoc* study; and
- To obtain point data for each crime inclusive of geographic location. This would make analysis more accurate for both administrative and academic studies and could be used to pinpoint police patrol in areas of high crime activity, as seen in some of the studies referenced. This would also provide more avenues for deeper and better studies into the evolving crime paradigm.

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Pivot III

Infrastructure and Spatial Planning Domain

Birkirkara Block Shadow Analysis

CHAPTER 14

Using Geographic Information Systems to investigate urban sprawl across three centuries in Victoria, Gozo

Andrew Formosa

Keywords

GIS, urban sprawl, built-up areas, non-built-up areas, grids

Project Aim

The aim of the project was to investigate three centuries of change in the urban sprawl of Victoria, Gozo. The project's objective was to identify, define and quantify built and non-built-up areas and subsequently quantify both areas across the last three centuries via an assessment of urban sprawl across Victoria.

Introduction

Area of study

Gozo, with an area of 68km², (National Statistics Office, 2019) lies to the North-West of Malta. Gozo, composed of 14 localities scattered around the island has a population of 33,388 inhabitants (National Statistics Office, 2020). Victoria, the capital city of Gozo, located in the middle of the island has been the centre of most of the past and recent history of Gozo. Its central geographical positioning in the centre of the island is an important factor to be considered, even because of Gozo's small area. In excavations at Independence Square in 1960, artificial accumulation of late Bronze Age, Punic and Roman levels were recorded (Trump, 2008). Mizzi (1996) notes that archaeological remains were found in Rabat dating to the Roman occupation.

Urban sprawl and importance of GIS

Urban sprawl can be conceptualised as rapid growth and spreading of physical developments in urban settlements, most of which for residential purposes which occur on undeveloped or peripheral land (Junaid et al., 2020). Economic activities and weak urban planning enhance urban sprawl. A key factor for urban sprawl is the rapid low-density outward expansion of cities which subsequently causes low density development (Bergantino et al., 2020). Some of the causes related to urban growth and sprawl include population growth, economic growth and industrialisation (Bhatta, 2010). Often, the densification of urban areas is related to green space loss or to a decline of green space provision per capita (Tappert et al., 2018). Urbanisation is seen as the main cause for the irreversible loss of land while city expansion has continued without established laws or directives (Criado et al., 2019). Swensen (2020) states that urbanisation leaves traces in the environment and reduction of arable land. Urbanisation also involves the conversion of urban fringes to built-up areas (Borana et al., 2020).

GIS is described as an effective way to input, store, update, process, analyse and display geographic information (Zunying et al., 2010). GIS provides deep insights into data and can identify patterns, relationships, and situations (Adkar et al., 2020). GIS is also popular for monitoring urban planning and urban development (Lu-Hong et al., 2011). Adkar et al., (2020) state that quantifiable proofs such as area calculations can be yielded through GIS. For better planning of village space, Yanfen et al., (2015) make use of GIS to identify construction-prohibit areas and construction-limit areas. Analysis of urban evolution and urban growth is calculated through GIS software and implementation of specific models (Mallouk et al., 2019). Such analysis can also be aided with multiple data formats including satellite images. The integration of remote sensing with GIS is widely acknowledged as a very powerful tool in analysing urban development (Elfadaly 2019).

Methodology

Data was collected from three main sources: historic maps, aerial photography, and satellite imagery (Table 1). To visualise change over time in the fabric of Victoria, a carefully selected corpus of six historic maps dating from 1804 to 1962 and two black and white aerial photographs were georeferenced and subsequently digitised. Information was digitised as vector layers showing the built-up and non-built-up areas. Slight differences in areas were noticed throughout the reference years due to the lack of precision in map drawing for the first four historic maps. The availability of satellite imagery with an adequate resolution covering the island of Gozo was only available for years 1998, 2008 and 2018 (all three images were 3-bands). For these years, remote sensing was used to identify built and nonbuilt-up areas. An ad-hoc field survey was conducted to verify the last reference year scenario and verify any areas which were difficult to identify through orthophotos. The field survey was carried out given the limited extent covered by the area under study

Table 1: Information on all reference year sources

Reference year	Type	Data extraction	Source details
1804	map	map digitisation	De Boisgelin, 1804.
1824	map	map digitisation	Worsley, 1824.
1907	map	map digitisation	National Archives of Malta – Gozo Section 1907.
1934	map	map digitisation	National Archives of Malta – Gozo Section 1934.
1945*	map	map digitisation	Public Works Department n.d.
1962	map	map digitisation	National Archives of Malta – Head Office 1962.
1978	aerial photo	map digitisation	Planning Authority 1978.
1988	aerial photo	map digitisation	Planning Authority 1988.
1998	Orthophoto	Remote Sensing	Planning Authority 1998.
2008	Orthophoto	Remote Sensing	Planning Authority 2008.
2018	Orthophoto	Remote Sensing	Planning Authority 2018.

The reference year is an approximate one given that no year was provided on the map. The source suggested that the year should be around the 1940's. The 1945 was selected as a mid-year representing the 10-year period.

The aim of the research was to identify and calculate the rate of urban sprawl. The analysis was done once the layers showing the built and non-built-up areas were finalised. A 100m^2 grid map was established to calculate the area of either built or non-built-up areas for each reference year. For each grid, the area covered by built- and non-built-up area was calculated. The percentages of built- and non-built-up areas of each grid were ranked into six categories. These categories were applied for all reference years under study to ease comparison and identify changes over time (Table 2). The streets area was identified and plotted on each map. The area taken by streets was not included in either the built- or non-built-up areas in all reference years The grid size of $100m^2$ was specifically chosen as the total area of Victoria is around $3km^2$ and thus giving a good representation of all different areas across Victoria.

Table 2: Categorisation of non-built- and built-up areas into percentage groups applied for all reference years

% of coverage of non-built-up area in each grid	% of coverage of built-up area in each grid
0	0
1-19	1-14
20-39	15-29
40-59	30-44
60-79	45-59
80+	60+

Results

Quantification of built-up and non-built-up areas across time

Figures 1 and 2 represent readings for all reference years for both built- and unbuilt areas. A total of 11 readings are provided, covering 214 years. From the first reference year (1804) till 1945, the changes in areas have been minimal. An increase in built-up areas was registered from 0.06km2 to $0.21km^2$. This minimal increase of 0.15 km^2 has been observed over 140 years. The shift from non-built-up areas to built-up areas has also been minimal, fluctuating between 2.59 km^2 to 2.43 km^2, resulting in a change of 0.17 km^2.

More changes were observed from 1962 onwards, with more non-built-up areas transformed as built-up areas. Over the last half century, built-up areas increased from 0.18 km^2 to 0.91 km^2. The increase in built-up areas after 1945 has been more drastic. This was corroborated by the decrease in non-built-up areas from 2.54 km^2 to 1.87 km^2 (Table 3).

Figure 1: Percentage of built-up and non-built-up areas for reference years 1804 to 2018

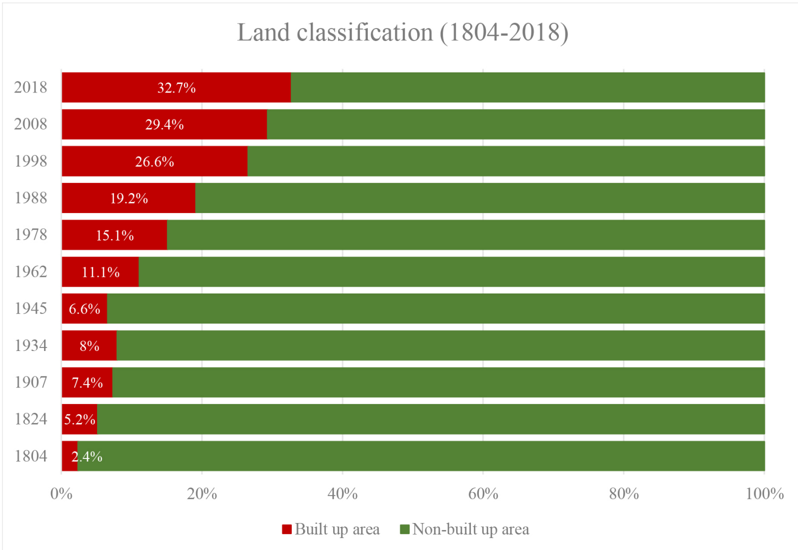
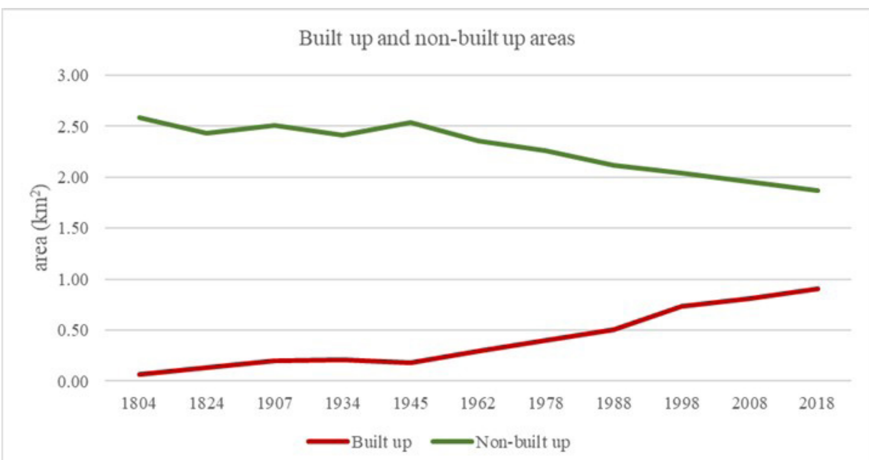


Figure 2: Built up and non-built up areas for reference years 1804 to 2018



Over time, the percentage of land uptake increased from 2.4% in 1804 to 32.7% in 2018. It seems that the post-war period in Victoria has been the catalyst for more land being taken up for building purposes. It is to be noted that a separate analysis needs to be done to assess any possible building restrictions or application of building restriction zones along the years (Figures 3 and 4).

Table 3: Total areas for built-up areas and non-built-up areas for both years covering reference years acquired from maps, aerial photographs and orthophotos

Year	Built-up area (km²)	Non-built-up area (km²)
1804	0.06	2.59
1824	0.13	2.43
1907	0.20	2.51
1934	0.21	2.41
1945	0.18	2.54
1962	0.29	2.36
1978	0.40	2.27
1988	0.50	2.12
1998	0.74	2.04
2008	0.81	1.96
2018	0.91	1.87

Figure 3: Bar graphs showing percentage of built- and non-built-up areas for all reference years

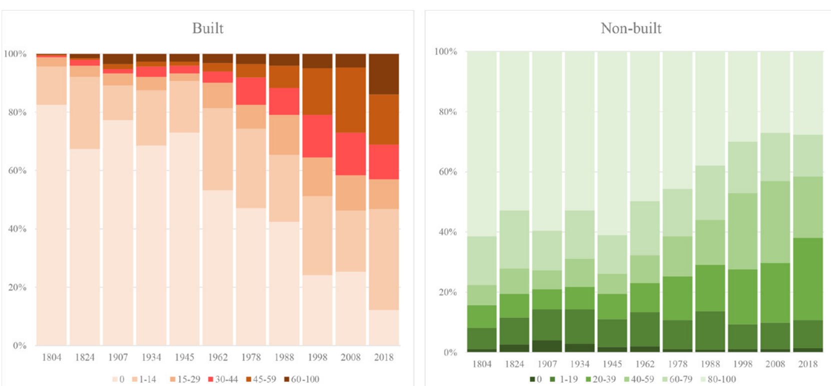
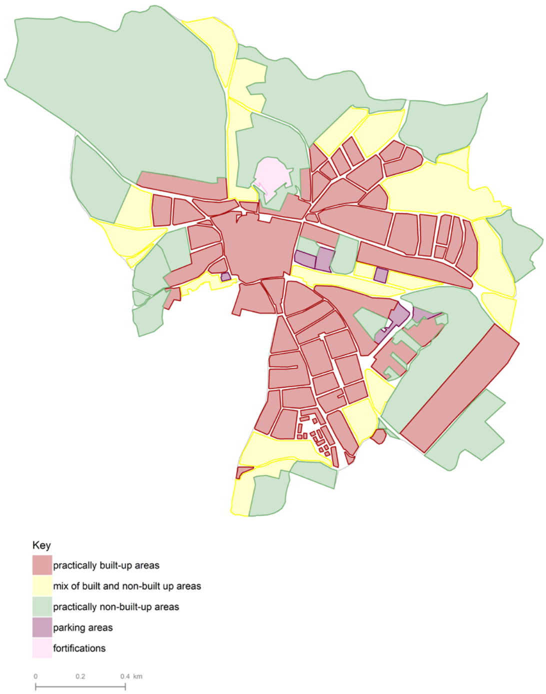


Figure 4: Classification of land area for reference year 2018



Use of grids for categorising urban sprawl spread

During the analysis, 100m^2 grids were created to better understand urban sprawl and the transformation of land to built-up areas (Figures 5 and 6). The percentage of built-up and non-built-up areas of each grid was grouped into six categories applicable for all reference years.

The built-up grid for reference year 1804 (Figure 5) showed how most grids register no built-up areas, with the sole concentration of high percentage built-up area grids around the old city of Victoria. The distribution of high percentage built-up grids increased by 1824. These were still concentrated around the old city and with minimal change up to 1945. Other grids were noted across various areas of Victoria however the percentage of built-up areas within such grids remained low. The 1962 grid map and data highlighted that land take-up started to increase at a faster rate. The spread of medium percentage built-up grid cells became more prominent and spread across Victoria. Such a trend was maintained throughout all the remaining reference years and intensified during the last reference years with 2018 showing the highest spread and concentration of land take-up.

Spread and concentration of non-built-up grid cells have a direct correlation with those showing land take up. The 1804 map (Figure 6) shows a quasi-total coverage of the territory with a high percentage of non-built-up area grids. The increase in land take-up has resulted in less non-built-up areas. By 1962, the coverage of grids indicates that a high percentage of non-built-up areas decreased. Instead, low to medium percentage grids of non-built-up areas started to increase across Victoria and moved considerably away from the old city centre. By 2018, all of Victoria – except for the North/North-West area – have registered low percentage grids of non-built-up areas.

Figure 3 (built-up area graph) highlights how the percentage of grids where no built-up areas were registered fell from 83% in 1804 to a mere 12% in 2018. This data confirms the extent of land transformation during the last three centuries. In tandem, with the decrease of grids having non-built-up areas recorded, more grids started to register at least a percentage of built-up. When analysing the last years under study, it can be observed that the intensification of built-up areas has occurred in zones which had existing buildings. This shift in the upper categories highlights how building has intensified within areas where development has already occurred.

The number of grids registering over 80% of non-built-up areas in Victoria decreased from over 60% to less than 30% from 1804 to 2018 (Figure 3). This data confirms how much land transformation has occurred and that land was used for building purposes. Given that more areas are being changed from non-built to built-up areas, instead of the 80%+ grids, other grids having less non-built-up areas have increased across the years. In 2018, the 40-59% category shrunk from 27% to 20% while the 20-39% category increased from 20% to 27%, certifying the take up of more built-up areas at the expense of green space.

Figure 5: $100m^2$ grid map showing percentage classification of build-up areas for all reference

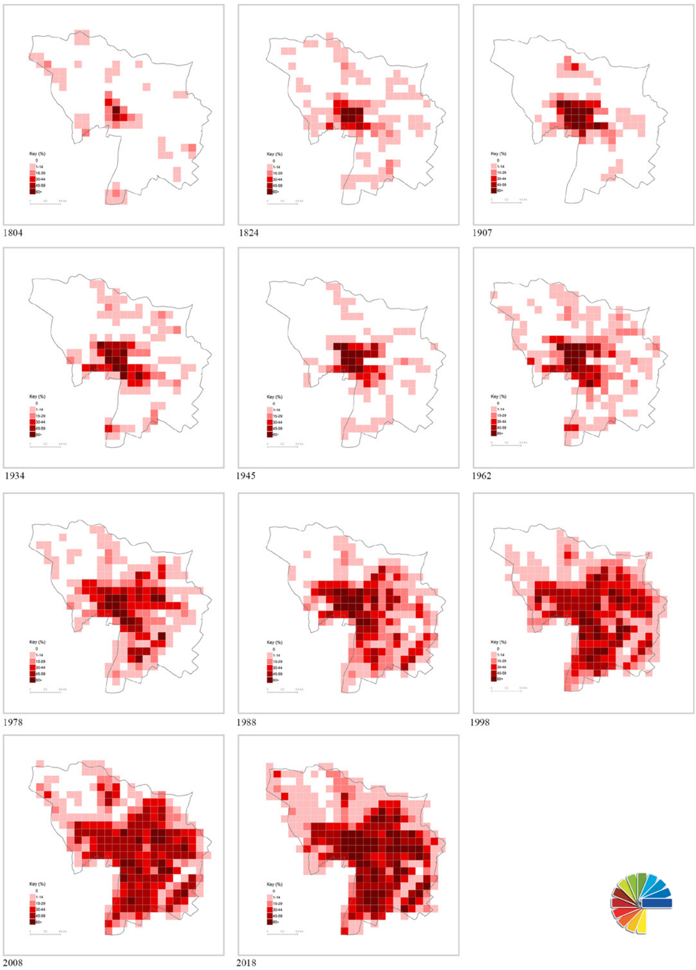
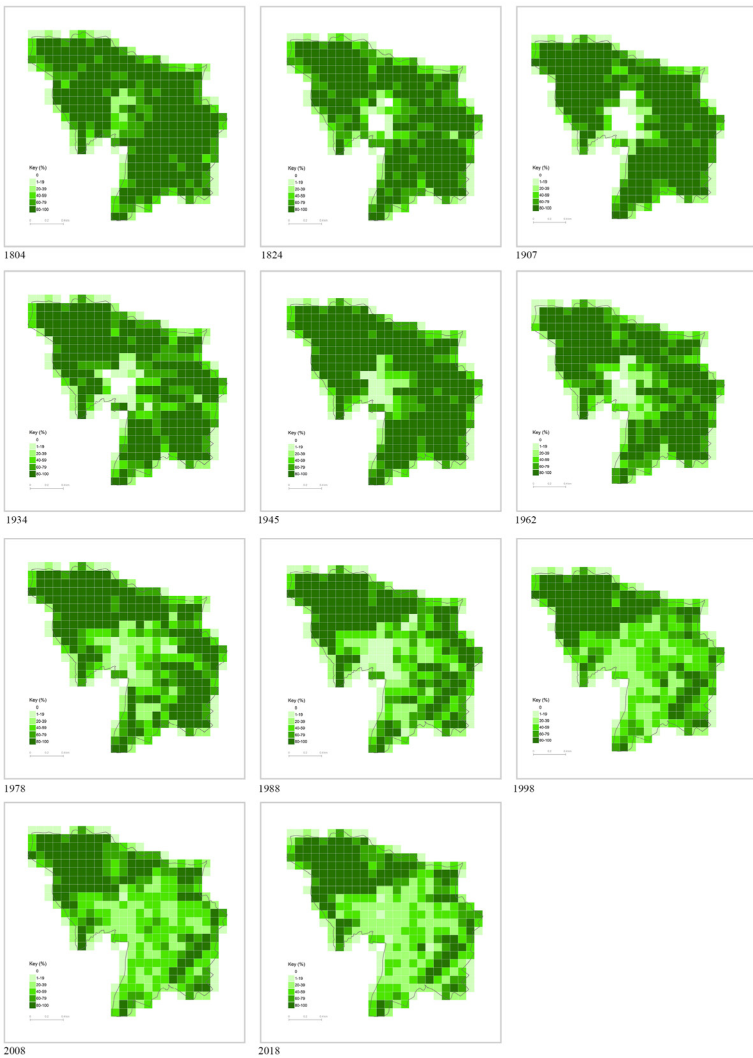


Figure 6: 100m^2 grid map showing percentage classification of non-build up areas for all reference years



Discussion

Throughout the study, it was emphasised how GIS not only shows, but also quantifies change over time. Tables and figures were provided to factually confirm the takeover of built-up areas over bare land. Table 4 is the summary of the latest data snapshot. Given the ability of GIS software to work with different layer types, it was possible to combine onsite field surveys with data achieved from orthophotos and manipulated through remote sensing technology. Field surveys helped to identify some of the key areas which otherwise would have been very difficult to identify - mainly fortifications and parking areas (due to limited 3-band data).

Table 4: Percentage of total areas as classified in Figure 4

Areas classified in Victoria	% of total area
practically built-up areas	32.4
mix of built- and non-built-up areas	18.2
parking areas	1.1
practically non-built-up areas	47.5
fortifications	0.8

Table 4 and Figure 4 highlights how GIS can be a very powerful tool for urban planning. It provided a 'stock-take' of the current situation in Victoria. The zones classified as a 'mix of built- and non-built-up areas' can be further analysed and taken in consideration for any further development. Entities responsible for urban planning can encourage new development to be concentrated within these zones. Positive discrimination incentives can be provided to landowners to develop building within these zones and thus, concurrently, discourage new buildings within the green areas. The availability of green spaces is found to be scattered around the area under study apart from a relatively large zone in the North-West of the settlement. During the field study conducted, it was noted that the area is a hill. Further studies on the area can be conducted using a Data Terrain Model and Data Elevation Model to explore the possibilities to retain such an area while transforming it into an organised public green area. All layers created through GI software can also be layered and amalgamated with other spatial layers pertaining to public entities responsible for planning.

The analysis was based on a mixed methodology approach, using old maps, aerial photography and orthophotos. It was highlighted how old maps may lack precision in presenting the entirety of the built- up area. Thus, when comparing with orthophotos based results, this might impinge on comparability. To tackle such issues, $100m^2$ grids were used to better represent different areas of Victoria and thus generalise any differences which might have cropped up due to non-representation. Grids were seen as the best option to compare built- and non-built-up areas achieved from 11 different sources. The application of the same grid and categories over the whole 11 maps ensured comparison across all reference years and thus detect – and quantify – change over time. GI software enabled the facility to apply the desired area of each grid cell by first taking into consideration the area under study. The categorisation of grids into five different sections (portraying different percentage of land area in each grid) helped to portray change over time.

Recommendations

The recommendations emanating from the study are as follows:

- The identification of a considerable large zone which is still a green area (North-West area of the settlement) - ensuring that it stays undeveloped - will be significant given the transformation of various green areas around Victoria to built-up areas. It is being proposed that such an area should not be subjected to land speculation. This recommendation is based on the fact that the North/Northwest area of Victoria is still nearly intact from any large development. This area can be transformed into an open space with minimal infrastructural intervention. Such consideration is being done without the knowledge of who is the owner of the identified area, being either the state or private individuals. More research on land ownership needs to be done.
- Application of this study on key important cities and settlements across Malta and Gozo to analyse and quantify urban sprawl. It is being assumed that apart from Victoria, other important settlements have experienced similar urban growth across time. All this analysis needs to be put in the perspective of the Strategic Plan for the Environment for the Maltese Islands aiming to control urban sprawl within defined development boundaries. The leading authority managing the mentioned plan should be entrusted to prioritise settlements across Malta and Gozo and conduct similar studies. Such studies should also identify various green spaces to be declared as non-building areas and instead turned into green open spaces.
- This study showed the importance of acquiring useful geospatial data. Increased awareness of the need for data collection and use of GIS for informed-based decisions is an indispensable prerequisite in land-use studies. This analysis exposed how the utilisation of different data sources was essential for the spatio-temporal analysis of Victoria. If the government envisages to extend this study, extensive research on secondary sources needs to be conducted. Furthermore,

the availability of new data for Malta (including lidar data) acquired through the Planning Authority's SIntegraM project need to be integrated in any future study by also focusing on the spatiotemporal analysis of building height across key cities and settlements.

- Identification of undeveloped areas within built-up areas to be used for further land take up at the expense of other zones still not reclaimed. Incentives and rebates can be introduced to landowners to encourage development within built-up areas.

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CHAPTER 15

Mapping water consumption demand in the Maltese Islands

Christian Debono

Keywords
Malta, Water Consumption, Water, GIS, Spatial Regression, GWR, OLS

Project Aim

The aim for this project was to determine which areas in the Maltese Islands require more attention for policy makers to base their water management plan on, while keeping the water supply sustainable and meet the water demand as required by the whole population.

- Perform a global regression analysis (OLS) with multiple variables and a local geographically weighted regression (GWS) to explore correlation and spatial variations between the different variables.
- Produce water demand maps for future years for all the Maltese islands and identify areas where high demand is expected.
- Critically evaluate the models used with alternative techniques and how future analysis can be performed.

Introduction

Literature Review

Water is one of the most important natural resources as it is viewed as a key to prosperity and wealth (Arbues et al., 2003). It is very critical for every urbanised area around the world; a failure to meet demand will lead to controversy which may develop into a catastrophe in the society; therefore, supply efficiency and demand management are very important for water supply authorities around the world (Worthington and Hoffman, 2008). Supply and management of water resources go hand in hand together since to supply water efficiently; management must be well setup and organised. The main objectives of water management as indicated by the United Nations (2015) is to provide sufficient clean water both in quantity and quality that meets the requirements for all uses, sustainable management of the resource and provision of sanitation and wastewater management for all. Luo et al., (2015) highlight the importance of improving water management and achieving more efficiency in geographical areas where water stress is becoming more frequent since there is growing concern about this; with a greater preoccupation in these areas (Tortajada et al., 2019). This stress i.e., increase in demand can originate from various reasons including economic, social, and environmental factors (Schleich and Hillenbrand, 2009). For instance, economic growth will increase the household income spurring the demand (Rinaudo, 2015). Similarly demographic changes such as ageing population, lifestyle change, and population growth will alter the demand (Schleich and Hillenbrand, 2009). Finally, climate change will affect the rainfall together with temperatures resulting in a demand increase since water demand will potentially increase in households especially for irrigation purposes (Worthington and Hoffman, 2008). In recent years global warming potentially had its impact too on the supply with the demand increasing while the supply decreases. The geographic location of an area together with its topography and land use influences the water demand, specifically in hot and arid locations. Bathrellos et al., (2008) highlights the water scarcity in the islands of Greece. These are almost identical to the Maltese Islands since they share the same Mediterranean characteristics, especially the location and both environmental and climate factors. Panagopoulos and Lambrakis (2006) attribute the scarcity problem with climate change and water mismanagement specifically in groundwater which is one of the main sources of fresh waters for these Islands. Similarly, Malta also depends on the ground water reserve. Water management policies are a major source in shaping up the efficiency and sustainability of water demand. Panagopoulos et al., (2012) argue that the absence of an integrated water plan in Greece may lead to water scarcity problems. Similarly in Spain which is a European country and share the same Mediterranean characteristics especially in the southern part of the country, Tortajada et al. (2019) criticise the policies and strategies used in Spain since they are very decentralised and are not adopted uniformly across the country, resulting in different management across all regions. This has led to different management plans which are not uniform in several areas of the country, resulting in data-scarce environments; since the data is generally scattered between government agencies, water companies and other actors (Bouziotas et al., 2015). In the Maltese islands this problem may not really be of a major concern since the water management is centralised and managed by the same corporation and it is integrated under the same uniform policies for all the Islands, while the data generated is centralised (WSC, 2020).

Spatial regression analysis has been identified by Schabenberger and Gotway (2017) as a form of data analysis technique where the focus is on modelling and understanding the mean function. In the context of water demand analysis, the term 'understanding' is gained when significant variables that play a role in water demand patterns are identified and analysed. Spatial Regression allows the modelling, examination and exploration of spatial relationships and can explain the factors behind observed spatial patterns; likewise, it can be used for prediction (Esri, 2020). The regression equation can be expressed as follows:

$$\gamma = \beta_0 + \beta_1 x_1 + \beta_2 x_x + \ldots \beta_n \beta_n + \in$$

Equation 1 The regression equation

Where γ is the dependent variable i.e., the water demand; x are the explanatory/independent variables i.e., the determinants of water consumption and β are the coefficients which represent the strength and type of relationship the explanatory variable has to the dependent variable.

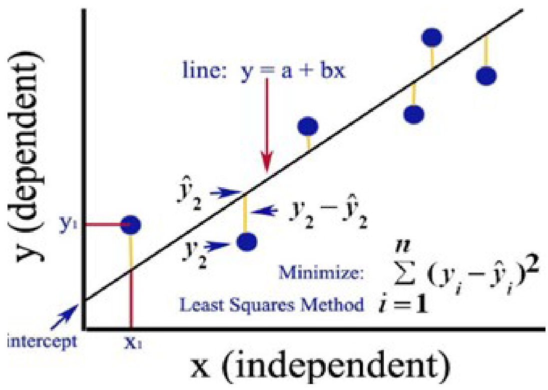
The use of Geographical Information Systems (GIS) has become an integral and useful tool in spatial and statistical analysis in water resource management (Udovyk, 2006). In water demand modelling the advent of geocoding and GIS allow data to be linked to household water consumption data to create rich and spatially explicit datasets (House-Peters and Chang, 2011), resulting in the compilation of rich datasets making possible the visualisation and quantification of water use patterns across different geographic areas (Lee and Wentz, 2008). The household level spatial data should be aggregated to a larger spatial scale to protect the privacy of the customer as House-Peters and Chang (2011) have stated that there is no industry standard to which water consumption data can be aggregated before becoming available for research. The analysis of these spatial blocks using spatial statistics will determine spatial patterns of clustering and dispersion of high and low water users across the geographical area.

The use of spatial regression analysis beginning with the Ordinary least square (OLS) and geographically weighted regression (GWR) will achieve the autocorrelation and determine spatial dependent variables within the study area and analyse the spatial relationship of the variables together (O'Sullivan., 2003). Wentz and Gober (2007) have used both Ordinary least squares (OLS) and geographically weighted regression (GWR) models to estimate the coefficients, which revealed the sensitivity of water consumption to the variation in the household and housing characteristics; these coefficients were then used to forecast water consumption in the desert city of Phoenix in Arizona. In the sections below a more detailed review of the Ordinary Least squares (OLS) and geographically weighted regression (GWR) will follow by identifying their main characteristics and applications.

Ordinary Least Squares (OLS)

Ordinary least square (OLS) is one of the best-known regression techniques; it has been widely used for model parameters estimation in various ecological modelling practices (Zhang et al., 2005). It is generally the starting point for all spatial regression analyses. The OLS model employs all variables at all locations to estimate the value of the dependent variable, hence all relationships in the study area are calculated equally (Wentz and Gober, 2007). Therefore, it provides a global model of the variable or process which is being understood or predicted. This method dominates the water demand literature from decades ago to recent years such as Billings and Agthe, 1980; Chicoine et al., 1986; Hewitt and Hanemann, 1995; Higgs and Worthington, 2001; Martinez-Espineira, 2003a. OLS assumes that observations are independent, which in contrast is often violated due to temporal and spatial autocorrelations in data; this yields a biased estimation of the standard errors of model parameters therefore misleading the significance of the model result (Fox et al., 2001). Figure 1 illustrates the OLS equation where it is used to estimate the coefficients by minimising the sum of the squared residuals; γ is the dependent variable which will be predicted while x is the dependent variable and the interception are the coefficients which need to be estimated.

Figure 1 Ordinary Least Squares Regression: predicted values in relation to observed values



Source: [adapted from] Gulve, 2020: online

2.3.2 Geographically Weighted Regression (GWR)

Geographically weighted regression (GWR) extends traditional regression models (Gao et al., 2006). It is a modelling technique that explicitly allows parameter estimates to vary over space (Brunsdon et al., 1996) i.e. the estimates of regression coefficients can be geographically different, by running regressions and estimated coefficients at different locations. As Brunsdon et al., (1996) have stated that it investigates the heterogeneity in data relationships across space. Contrary to the OLS model, which is a global model; the GWR is more localised making it a local model. Figure 2 shows a basic illustration using population and income as independent variables to calculate crime and shows how the GWR is presented as a local regression model.

Figure 2 The coefficients of population and income as allow to vary across space

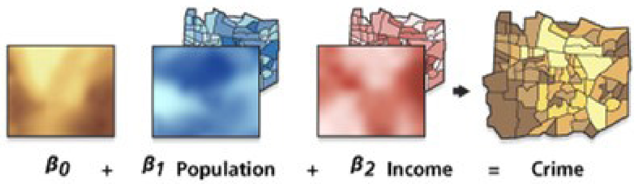
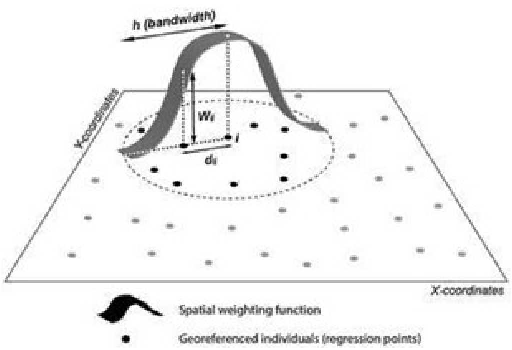


Figure 3 shows a more schematic representation of the GWR and its spatial parameters where it integrates multiple local regressions within an overall framework.

Figure 3 Schematic representation of the GWR and its spatial parameters



Source: [adapted from] Feuillet et al., 2015: 6

Fotheringham et al., (1998, 2002) give a general equation for a basic GWR model as follows:

$$\gamma_i = \beta_{i0} + \sum_{k=1}^{m} \beta_{ik} x_{ik} + \varepsilon_i$$

Equation 2 The basic equation for GWR

Where Y_i is the dependent variable at location *i*; X_{ik} is the *k*th independent variable at location *i*; *m* is the number of independent variables; β_{io} is the intercept parameter at location *i*; β_{ik} is the local regression coefficient for the *k*th independent variable at location *i*; and ε_i is the random error at location *i*.

Failure in incorporating spatial heterogeneity will result in biased coefficients and a loss of explanatory power (Bitter et al., 2007). In a nutshell any georeferenced variable being dependent on or independent to the model can be estimated. These are fitted around a number of prediction points in the study area and each data point is inversely weighted by its distance from the regression point resulting in more weight given to the points which are closer to the regression point by those which are further away as shown in Figure 2. In their white paper 'Geographically weighted regression' Charlton and Fotheringham (2009) state that as a minimum output the GWR model will produce a parameter estimate together with associated standard errors at the regression point. If the regression points are the same as the sample points, then it produces predictions for the dependent variable, residuals and standardised residuals on the other hand if the regressions points are not the same and there are no independent variables available for the regressions point then the parameter estimates, and standard error will be only available (Charlton and Fotheringham, 2009).

Methodology

This research project was an investigation of water consumption of the Maltese Islands. Key elements included the establishment of the determinants of water consumption, and the use of regression methods to predict potential demand in the future. The main data used for the research was the mean average water consumption data for each household, which was aggregated for each Local Administrative unit, thus guaranteeing the privacy of everyone. This was the most important data used for this research since it provides monthly variations to show how water demands on the island change throughout the year. It also served as the dependent variable for the prediction techniques applied i.e., Ordinary least squares (OLS) regression and geographically weighted regression (GWR).

In this study the local administrative units (LAU) of the Maltese Islands were used for data aggregation, ensuring data privacy for household data, eliminating the exact location of each water meter. Apart from the consumption data, other data was required for this study which was primarily used as an independent variable for the methods to be applied as mentioned in the previous chapter. The climatological data of the past ten years of the Maltese Islands was used. One major drawback of using such data in this research is that the climatological data provided was collected from one location only. Thus, given the small size of the Island there is no variability in the data, which will not result in any significant changes across different locations. Therefore, to help include the climate variation in this research the data was grouped into seasonal data. The average number of persons living in each household was aggregated with each LAU together with the price class count of each household. The price class was used to classify the meters for households and includes residential, non-residential and domestics classes (REWS, 2014).

The years selected for this research were 2010, 2015 and 2020. Each year had a specific event associated with it that may have a direct impact on the water demand, which have occurred in the Maltese Islands:

I. 2010 – The year in which smart water meter technology was introduced in Malta. This was a major shift in gathering meter reading data in which manual meter reading began to be eliminated and remote meter reading began to take over (Water World, 2011).

II. 2015 – In mid-2014 the water price was reduced in Malta. Therefore 2015 was the first full year in which the water tariff was lower than previous years. Thus, this year should be the first indicator if the change in water tariff price has affected the demand or not (MRA, 2014).

III. 2020 – This year was particular since the global pandemic of Covid-19 affected the whole globe including Malta. The data of this year should indicate if the pandemic has also affected the water demand, since there were several lockdowns, the tourist industry came to a standstill and many people had to change their lifestyle because of the pandemic (Grima, et al., 2020).

Analysis

The two main methods that are applied in this research are the Ordinary Least Square (OLS) and a Geographically Weighted Regression (GWR) analysis. First the OLS was applied as a global model followed by the GWR which is a more localised model that estimates the coefficient of the determinants of water demand and analysed the spatial relationship of the explanatory variables together (Kupfer and Farris, 2007). The results from these models were used to forecast the future water demand of the Maltese Islands. Ultimately, the result of this forecast was mapped and water demand maps for the Maltese Islands were produced.

Ordinary Least Squares

The ordinary least square (OLS) model is generally the starting point for all spatial regression analysis since it evaluates the relationships between two or more feature attributes (Calderon, 2009). These relationships help to understand what is going on in a place i.e., where the water demand is particularly higher and predict where more demand is more likely to occur. In this model variables at all the different locations which are used to estimate the dependent variable, are calculated equally across the study area (Wentz and Gober, 2007). In this study the dependent variable for the OLS model was the mean water consumption of each LAU. The independent variables were the mean number of persons per household which identifies if the number people in a household will affect the consumption. The other independent variables are the number of households per price class in each LAU. These variables should reflect if the different price classes affect the consumption. Various studies including Sauri (2019), Corabella and Sauri Pujol (2009) and Shaw (2006) indicate that water price has a direct impact on consumption. Equation 1 represents the equation applied in the OLS model:

$$Q1Mean = \beta_0 + \beta_1 * (NopMean) + \beta_2 * (Residential) + \beta_3 * (Nonresidential) + \beta_4 * (Domestic) + \in$$

Equation 1 The OLS regression equation

Geographically weighted regression

In this study the basic GWR equation by Fotheringham (1998, 2002) was applied for every observation in the dataset to predict the water demand. The equation i.e.

$$\gamma_i = \beta_{i0} + \sum_{k=1}^{m} \beta_{ik} x_{ik} + \varepsilon_i$$

Equation 2 The basic GWR equation

Where Y^i is the dependent variable at location *i* i.e., the mean consumption of each LAU; X^{ik} is the *k*th independent variable at location *i*; *m* is the number of independent variables. The independent variables to be used in this models are the average number of persons in each house, the price class data (residential, non-residential and domestic) and the climatological data (average rainfall and mean temperature for the quarter) β_{io} is the intercept parameter at location *i*; β_{ik} is the local regression coefficient for the *k*th independent variable at location *i*; and ε_i is the random error at location *i*.

GWR is an extension of the OLS model (Meik and Lawing, 2017) though these models are opposite to each other since, GWR is a localised model where the parameter estimates vary over space and regression equations are performed over different geographic locations (Brunsdon et al., 1996) and the OLS is a global model fitted to all the study area and its processes are independent from the location. In global regression models such as the OLS results are unreliable when two or more variables exhibit multicollinearity (multiples values are redundant) while in GWR a local regression equation is performed for every feature in the dataset at each location and weighted to values (in this case weighted by an inverse distance) of nearby values (Wheeler and Tiefelsdorf, 2005). There are two different kernel types i.e., fixed, and adaptive. A fixed kernel defines a geographical weighted matrix with the assumption that the bandwidth is constant across the whole area while the adaptive kernel applies a large bandwidth only when data is sparse and a smaller bandwidth when data is dense (Yacim and Boshoff, 2019). These nearby values is sampled from a fixed distance from the observation i.e., fixed kernel, since the observation area in this study is very small. The kernel is the size of the moving window, generally less than the region size. The local modelling in GWR does not allow extrapolation beyond the region in which the model is established but it allows the parameters to vary locally within the study areas hence they can provide a more appropriate and accurate basis for descriptive and predictive purposes.

Results and Discussion

Water smart meter introduction in 2010

The scope of using the 2010 dataset was driven by the introduction of smart water meter technology in Malta (Water World, 2011). During this period water consumption data was being collected in parallel using two different techniques, i.e., the new remotely meter reading through RF antennas technology and the manual meter reading where water meters were read on location periodically by WSC personnel. A global spatial regression was applied to the whole datasets as described previously. The statistical results of the models i.e., the model performance (r^2) and the residual output maps for each dataset are almost identical. As highlighted previously when all the results are compared together seasonality is not reflected in the residual maps, since no seasonal data was used and that the temporary of the other variables used is yearly, meaning that there is no variance except for the water consumption value. The OLS residual maps show that the majority of the LAUs are within the range of -0.5 to 0.5 while the central part of Malta, which is the most populated part, tends to be on the lower side of the residual scale averaging the values of -1.5 to -0.5. On the other side, the residuals in the island of Gozo are more distributed differently around the island. The average r^2 of these models is 0.35 meaning that 35% of the variation in the output variables are explained by the input variables. The average adjusted r^2 of the OLS model for all the data sets is around the value of 0.31, which means that the additional input variables used in the model are contributing with a value of 31% to the model. This result can be attributed to the choice of variables used since these are all population related, contrary to the variables suggested by Schleich and Hillenbrand (2009) in which they used a mix of economic, environmental, and social variables and achieved an adjusted value of nearly 0.70; to determine the main water determinants of Germany.

The datasets were then modelled using GWR on a local basis for each LAU. As various studies conclude including Gao et al., (2006), Bitter et al., (2007), Wentz and Gober (2007), and Liu et al., (2019); GWR should show improvement over OLS since it is more able to predict the water consumption and show its spatial heterogeneity (Nazeer and Bilal, 2018). In this case the results were almost identical between the two modelling techniques, were the r^2 and adjusted r^2 values are the same i.e., 0.31 and 0.35 respectively. Thus, this shows that this contradicts other studies since no improvements are noticed in GWR modelling. Several factors could be affecting these results. This could have resulted in a contrast in the data temporality, where some of the consumption data was collected instantly and another selection was collected periodically or estimated, there these will not reflect the real picture in the data provided.

Water tariff price reduction in 2015

The next set of datasets processed were those representing the water consumption during the year 2015. Contrary to the previous datasets, during this period the parallel data gathering of both automated and manual data was being eliminated and almost all the water meters were smart meters, meaning that water consumption data was being collected remotely and immediately without any manual reading. This year was particular in that it was the first full year where the water tariff prices were reduced from the previous years (MRA, 2014). Therefore, there was the expectation that water consumption might rise. Analysing the results obtained from the OLS model, it can be observed that both the r^2 and adjusted r^2 has decreased from the 2010 results, with an average value of 0.29 and 0.24 respectively. Like the previous residual maps, no difference is observed in seasonality while there are a very few minimal changes in some LAU's when comparing the residual maps. This shows that there was no major shift in the consumption with regards to the tariff decrease since the results remained constant throughout both years although a yearly increase is observed there was not a significant increase instantly. This can prove Arbues et al. (2003) conclusion in which the water price does not affect the demand significantly given it is an essential life-giving resource and water is a necessity for daily living, no price increase would curb drastically the water demand.

The 2015 GWR results show a significant increase observed both in the r^2 and adjusted r^2 in which these were increased to an average of 0.70 and 0.51 respectively. This could be an indication that the automated readings which were almost fully implemented five years after the introduction of smart metering are gathering consumption data more precisely instantly. The tariff price could be a factor that affected this result primarily due to the use of price class data as part of the independent variables, which classifies the number of households in each class. This result shows that localised regressions improved for each

LAU separately and that the variables used contributed better than when performed in the OLS model (Villar-Navascués and Pérez-Morales, 2018). Even the residual maps, show a variation from the year 2010. Although seasonality is not reflected again here given the same reasons of the previous datasets i.e., homogenous independent variables throughout the year.

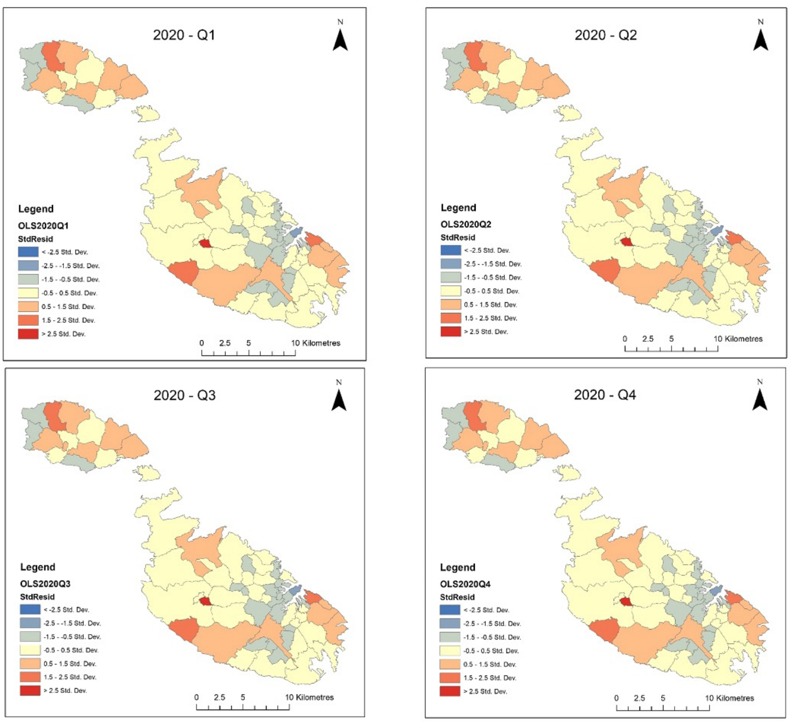
The Maltese Islands experienced a significant population increase since 2010 as shown in the estimates published by the NSO (2020) in Table 1. The estimated increase from 2010 to 2015 is around 40,000 people which is quite a significant number for the size of Malta. The residual maps show a major shift in the southwestern part of Malta where the residuals are mainly between the values of 0.5 to 1.5, while the central part is more in the average range of -0.5 to 0.5. Another major shift can be observed in the northern tip of the Island in which the standard residuals have both fluctuated to the negative side of the scale. These shifts could be the effect on the population increase experienced in the last years as Malta was the highest country in the European Union with the largest population growth (Macdonald, 2019); thus, the population increase had a direct impact on the water demand.

Impact of the Covid-19 pandemic in 2020

This year was very particular all over the world since the global pandemic of Covid-19 (Cheval et al., 2020) has hit the entire world population and most of the people had to adapt to a new type of lifestyle. This included various lockdowns where people were required to stay indoors and resulted in a steady decrease in various economies, Malta was not an exception (Reuters, 2020). The first thoughts of such drastic changes are that this will immediately result in an increase in water use since people are now spending more time indoors. Since various industries had to stop a reduction should be expected on that side too (Alvisi et al., 2021). These results should indicate whether this was the real outcome of the pandemic in relation with water consumption and demand. The OLS modelling was first applied as done in the previous years. The statistical output of both the r^2 and adjusted r^2 are of values 0.26 and 0.21 respectively.

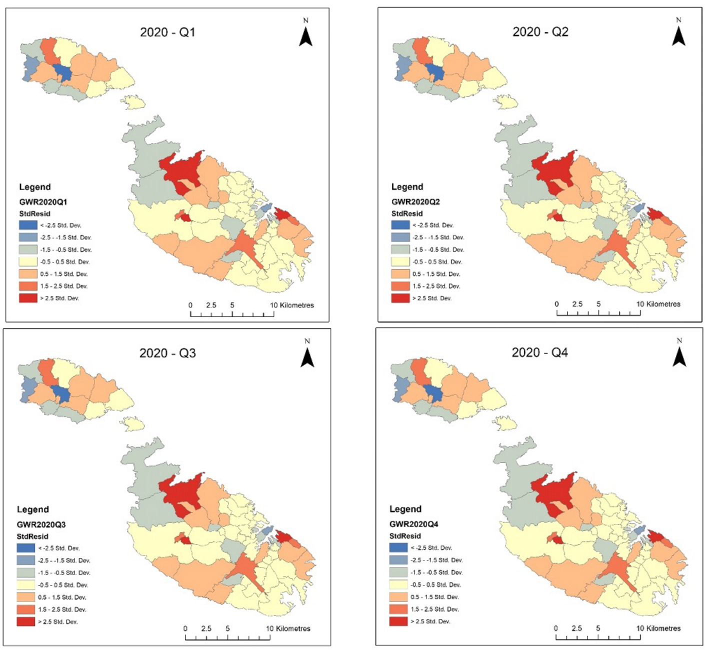
This result is almost identical with the same values as achieved in the previous years; meaning that the explanatory variables are not contributing very positively to the model with an approximate average of 21%. The main reason for having such results could be attributed to the choice of independent variables, as observed in previous years. Given this year is particularly unique, ideally other variables should be introduced which may reflect the social life during this period mainly variables including number of children in households since schools were shut during this period, and number of people working from home. Environment related variables could be included such as the availability of gardens and pools in the household since people had to entertain themselves in their own household. Wentz and Gober (2007) found a direct relation in water demand in households containing pools and gardens. The residual maps (Figure 4) as generated by the OLS models; does not show seasonality mainly due to the lack of climatological data used. The majority of the LAUs lay in the same value of standard residual of -0.5 to 0.5, with the central harbour areas leaning more on the negative scale of -1.5 to -0.5. The values in the island of Gozo practically remained the same through all the datasets. This result could be the use of homogenous population data throughout the year for price class amounts and number of persons.

Figure 4: The maps of the Standard residual from the OLS model for each quarter of year 2020



The last phase of this research was the GWR modelling of the year 2020 datasets. Figure 5 indicates that the statistical outcome for all the quarters is different from each other. This is observed for the first time in this research and can be related to the different phases of the lockdown period as reflected in the r^2 value of each quarter. Overall, the r^2 and adjusted r^2 values have increased significantly from the OLS models. Beginning with the first quarter the values were of 0.38 and 0.32 respectively; increasing to 0.68 and 0.49 in the second quarter; to 0.74 and 0.70 in the third quarter and lastly a marginal decrease in the last quarter with value 0.68 and 0.49. These values suggest that the performance of the GWR model was far better than the OLS; especially in the variations observed quarterly as Zhang et al., (2005) have concluded that GWR modelling produces more accurate predictions for response variables and more desirable spatial disturbance for model residuals. The maps in Figure 5 with the residuals output of the GWR models, do not show the variations in the seasonality as observed previously in the other years but show a different scenario when compared to the OLS maps. The number of LAUs with a standard residual value of -0.5 to 0.5 has decreased in some areas while an increase in the number of LAUs with a value of 1.5 to 2.5 can be observed.

Figure 5: The maps of the Standard residual from the GWR model for each quarter of year 2020



Observations

The main observation from all the results is that seasonality is almost not reflected at all by the data used for this research, the main reason for this is that no local climatological data was used. Given the very dry periods the Maltese Islands experience especially in the summer period (Galdies, 2011) and the effects of global warming. It was expected that this should be reflected in the results achieved, especially in quarter 3 datasets which covered the summer months though no direct climatological data was used. Various studies have indicated that dry months and water scarce environments do affect the water consumption with an increase in demand. This has been shown in the study in Spain by Martinez-Espineira and Nauges (2004) which has concluded that climate does influence the water use in dry areas.

The main reason for achieving such a result was that the meteorological data was not adequate enough for this study i.e. to be used as an independent variable in all the models. The data lacked variations across LAUs. Thus it could not be processed in the models since average mean temperature values and precipitation amounts were identical for every LAU and both the OLS and GWR models were not able to process the data giving several processing errors during the process. Apart from lack of proper climatological data, this could also be the result of water saving practices used in Malta, which mainly include water wells which serve as reservoirs by collecting rainwater in the wet season and then used in the dry period in summer, especially for gardening and cleaning. Schleich and Hillenbrand (2009) used the share of households with wells as one of their independent variables to determine the water demand in Germany.

Since Malta has a very small surface area of 316km^2, it is almost unfeasible to have official weather stations across the island, therefore the climatological data is officially processed for the whole Islands. Therefore, it is not possible to compare the results with the ones in which climatological is different across the whole countries including the studies by Sauri (2019), Martinez-Espineira and Nauges (2004), and Cubillo and Ibanez (2003) which all focused on the water demand in Spain in relation with the local climate. Since climate data is important in water demand analysis, the Water Services Corporation could invest in small weather stations in each LAU and collect the data accordingly which then can be used in similar future studies.

Another factor affecting the results is the population data used. All the explanatory variables used as independent variables in the models are mainly population related i.e., the mean average number of people living in each household (household size) in each LAU and the number of people in the LAU per price class. The price class is the indicator showing in which tariff bandwidth the households fall in. The main reason for using such variables was to determine the effect of household size and to investigate whether the water price is affecting the consumption in relation to each different price class. The use of population related variables has been included in Wentz and Gober (2008) study. The model performance for all the dataset using OLS shows that that the average multiple r^2 and adjusted r^2 are 0.30 and 0.25 respectively when comparing the results of all the years; meaning that these explanatory variables explain around 25 percent of the water consumption. This result reflects the explanatory variables used since these are all related to the population and the temporality of the data is yearly, meaning that each quarter has the same value for a particular year.

The performance of the GWR models show that the average r^2 and adjusted r^2 are of 0.55 and 0.44 respectively, resulting in an improvement over the performance of the OLS model, meaning that the explanatory variables used justify around 44 percent of the water consumption. This result is due to these explanatory variables attributing to the water consumption, but it is still quite low when compared to the results of other similar studies such as the study by Wentz and Gober (2007) in the city of Arizona which have resulted in a high value OLS r^2 of 0.64 and GWR r^2 of 0.85. It can be concluded that these results indicate that there was no point to undertake seasonal analysis, since it was not reflected, and the only data variation was in the dependent variable i.e. the water consumption. The decision to make this kind of seasonal analysis was an attempt to reflect the seasonal variation since the actual climatological data was not fit for this analysis.

The results do show that the population explanatory variables used in the models are attributing to the water consumption but are not enough to have the whole perspective of the real situation with regards to water demand. It is being suggested to use other variables to determine the consumption and not just rely on the ones which are related directly to the population. Mainly as discussed before the climatological data should be included directly since it could contribute to show the different variations in the seasons and determine the effects of dry periods and of global warming, it is important that these must be collected locally for each LAU as mentioned previously. Apart from the pricing classes used other economic related variables can also be used to analyse whether these affect the consumption. Such variables can include the average income of households and the educational levels of individuals as included by Frankczyk and Chang (2009), Harlan et al., (2009) and Schleich and Hillenbrand (2009). Other household related variables will be ideal to be included as explanatory variables including if households contain swimming pools, gardens, and water reservoir wells as included by Wentz and Gober (2008) and Schleich and Hillenbrand (2009).

Recommendations

Based on the results obtained, the methodology used in this study requires further improvement, especially in the inclusion of other independent variables. One main recommendation is the inclusion of more independent variables to have a clearer picture on the real determinants of water consumption. House-Peters and Chang (2011) presents a list of the most common variables which are used in different spatial water demand analyses. Apart from population related variables used in this research, other variables could also be included including economic and environmental-related variables. As mentioned, previous climatological data available is not fit for this purpose. To solve this issue, it could be ideal if local weather stations will be installed in each LAU by the WSC. This could contribute to the collection of climatological data which can be later processed and used for similar studies and avoid the reliance from other sources to get the data.

Another factor which is recommended for further analyses in future studies is the implication of water consumption by households that have rainwater reservoirs/wells, private swimming pools and sizeable gardens. Currently no official data are available on this.

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CHAPTER 16

Spatial algorithms for landscape change detection

Steve Zerafa

Keywords

Remote Sensing, Sentinel 2 datasets, Satellite images, NDVI, Land Classification, change detection, crop patterns, pixel analysis

Project Aim

The purpose of this project was to develop methods based on Normalized Difference Vegetation Index (NDVI) quantitative variations, as obtained from the Sentinel-2 satellite images, to measure the area of rural lands, to detect changes to the land's surface, and to identify fields in the Maltese Islands that are used for the cultivation of grape vines and potatoes.

Introduction

Land classification is the process to display information and changes occurring in the land cover, which are derived from natural events or from human-derived processes. Land classification can provide fundamental information, such as land vegetation patterns, crop yield estimates, forest management, and urban development monitoring (Foley 2005). The Sentinel-2 satellites are widely used to work out land use classification through remote sensing techniques (Phiri 2020). These satellites are part of an Earth observation mission, which falls under the European Union's Copernicus Programme that systematically acquires optical imagery at high spatial resolution (10m to 60m) over land and coastal waters. The Sentinel-2 mission is a constellation of two twin satellites, named Sentinel-2A and Sentinel-2B, and are equipped with a multispectral instrument. The satellites fly at an orbit of 786 km altitude and revisit the Maltese Islands every 10 days. Therefore, an image for the whole islands is available every five days.

However, the central and southern part of Malta, and the North-West part of Gozo are at an advantage since these areas get extra satellite revisits due to an overlap of satellite swath from adjacent orbits. The sensor on-board the Sentinel 2, which takes the images, is a multispectral sensor that can deliver 13 spectral bands with a resolution which varies from 10 to 60-meter pixel size. Each band has a different wavelength, and the most widely used bands are red, green and blue (RGB) infrared red (IR) and near-infrared red (NIR). The data extracted from sentinel 2 spectral bands is used to display photos and colours, and to use in mathematical equations to generate information on forests, agriculture and water, among other uses. The most often used index for land classification is the Normalised Difference Vegetation Index (NDVI) (Tucker et al. 1981, 1999) which represents the well-known normalized ratio between the red (R) band and the near infrared (NIR) band (Rouse et al., 1973). This dimensionless index, as described by Weier and Herring (2000), can be used to estimate the density of vegetation greenery. The NDVI focuses on the vegetation green biomass colour, which is found on crops, trees and plants leaves. The NDVI does not detect, reflect or take into consideration the synthetic green produced by artificial colouring and paints.

The equation for the calculation of NDVI is:

$$NDVI = \frac{NIR-R}{NIR+R}$$

Methodology

Area of study - The Maltese Islands:

The Maltese islands constitute the area of study which is 316km². The islands are located at coordinates 35.9375° N, 14.3754° E. The natural landscape of the islands is dominated by karstic rock formations, nearby water bodies, and Mediterranean flora and fauna which is predominantly rather inconspicuous (MEPA, 2004). The change in the Maltese landscape is caused by a variety of natural and non-natural factors including rock erosion, soil erosion, the latter caused by heavy rains and flooding, construction activity and farming, and by planting and harvesting various trees and crops in various locations, thus modifying the appearance of rural and agricultural areas, and creating valuable habitats for wildlife

The Maltese Islands' surface landscape undergoes a significant colour change from winter to summer and vice versa, because of the positioning of the islands, and anthropogenic activities. The true colour transformation is portrayed in Figure 1. In late winter and early spring, the true colours of the Islands' landscape are largely green with shades of brown in rural areas and white-grey colouring in urban areas. In summer, the true colours in rural areas are browner with shades of orange; while in urban areas, the colours tend to be off-white and grey. This highly dynamic change has a direct impact on the magnitudes and shifting of the remote sensing indexes.

Figure 1: The variation of true colours of Malta, Gozo and Comino as taken from Sentinel-2 in March 2019 and August 2019

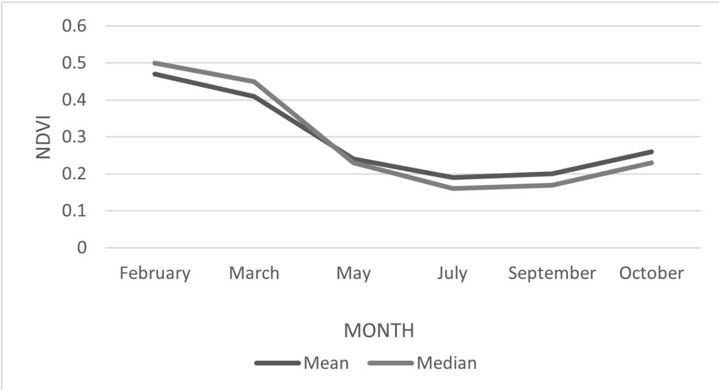
Acquiring Data

Multiple Sentinel-2 datasets were acquired from the Copernicus Scientific Hub, (The Copernicus Open Access Hub) maintained by the European Space Agency (ESA). The images from the Sentinel-2 constellation were acquired at a 1C processing level, and an atmospheric correction was computed on all datasets with the Sentinel Toolboxes Application software.

Extracting the yearly NDVI trend over the Maltese Islands

A foundation analysis was required to highlight the NDVI values for the whole Maltese islands, its relationship with seasonal changes, including rainfall variations, and its annual temperature variation. For this analysis, six different images taken over Malta from various months in 2019 were used to calculate the mean and median values of the NDVI for the Maltese islands as shown in Figure 2. The R and NIR spectral data were extracted and averaged to obtain the data on NDVI variations.

Figure 2: The yearly NDVI trend over the Maltese Islands



The baseline analysis established that the NDVI scale for the Maltese habitat is highly dynamic, so much so that the mean value was relatively close to the median value throughout the whole year. Analysis also showed that the NDVI graph reflected exactly the true vegetation colours of the islands as shown in Figure 1. The NDVI in the Maltese Islands was at the highest in late winter/early spring, with mean and median readings close to 0.5 when the Islands experienced the most vegetation 'greenness' in colour and were at the lowest in summer when the islands experienced the lowest 'greenness' and both NDVI readings of mean and median measuring less than 0.2.

The NDVI Table 1 represents in more detail the scale of the NDVI throughout the seasons and its representation of plants, trees and other surface bodies, for the winter / spring and summer periods. The results listed hereunder were concluded from manually observing hundreds of data points from sentinel 2 images and mapping these data points to ground truth data by visiting each data point location over a period of 12 months and observing and logging the type of actual ground cover that was present there. The land cover types listed in Table 1 represent the categories that were considered during the ground truthing. The derived NDVI values showed that for all the types of land cover, the NDVI shifts to very low numbers during summer, thus the boundary values from one land cover type to another are very close and, in some instances, they overlap each other. This was mostly visible when values were derived for bare land with some soil patches and soil with no vegetation. The NDVI numbers were almost identical. This is because the vegetation in Summer is very low in all categories and therefore NDVI values tend to overlap since NDVI is directly proportional to the vegetation density.

Table 1: The grading and variation of NDVI scale for the Maltese Islands

Variation of NDVI scale from Spring to Summer		**Types of land cover**
Winter - Spring NDVI values	Summer NDVI values	
< 0	< 0	Water bodies, pools, water brooks
>.03 and <0.2	>.03 and < 0.11	Tarmac, Concrete Building, sand, rocks
>0.18 and <0.25	>.07 and <0.15	Bare land with soil,
>0.25 and < 0.3	>.07 and < 0.19	Soil, vegetative surface with no vegetation
>0.35 and <0.6	>0.2 and <0.3	Shrub lands, wild plants on cliffs,
>0.3 and <0.4	>0.2 and <0.33	Vegetation from crops at the early stages of crop cycle
>0.5	>0.3	Mature crops, dense grass and trees, vegetative valleys

Selection of Vegetation NDVI categories

Once the baseline analysis was computed, another study was carried out to establish the surface vegetation changes over a period of two years (2017-2019). Two Sentinel-2 images were used. The images were taken on 09-03-2017 (dn1) and 24-03-2019 (dn2) at 9.50am GMT, both in March, 745 days apart, during the season when the Islands experience the full greenness colour. Both images contained 0% cloud cover and the resolution for each pixel in each image was at 10 x 10-metre. Millions of pixel information were extracted from both images, and the NDVI value for each pixel for both images was calculated and sorted into one set from a group of 4 to obtain a basic classification. The 4 groups selected for classification were (1) 'Urban' consisting of sealed surfaces such as tarmac, concrete and rocks; (2) 'Low vegetation'; (3) 'Medium vegetation'; and (4) High vegetation'.

A different shading for each pixel represented into the group was applied to better visualise the different categories or groups of vegetation density and non-vegetative land cover as displayed for year 2019 (Figure 3) as listed:

1. Urban Areas: No vegetation areas. Include tarmac, concrete, and bare rock. The NDVI values for this range were <0.3

2. Low Vegetation: vegetation which is normally formed in arable land, rocks, and cliffs. The NDVI values for this range were >0.3 and <0.45
3. Medium vegetation: Represents crops at initial cycle and shrubs lands. The NDVI values for this range were >0.45 and <0.6
4. High Dense vegetation: Represents mature trees, and crops at mid- and end of cycle. The NDVI values for this range were >0.6

Table 2: The classification of NDVI over the Maltese islands from 2017-2019

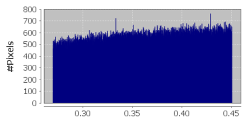
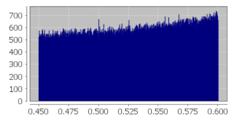
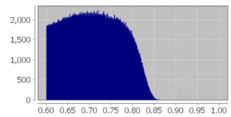
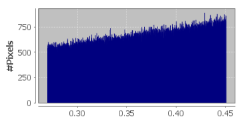
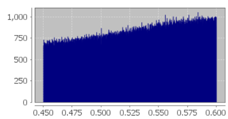
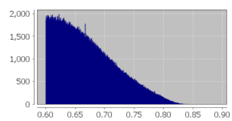
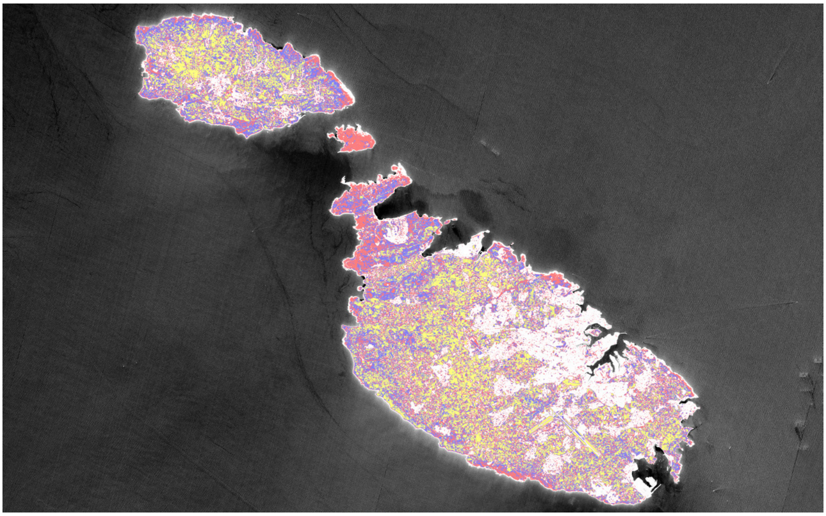
	Low Dense Vegetation	**Medium Dense Vegetation**	**High Dense Vegetation**
2017 Number of pixels vs NDVI			
Figure 3 legend	Red	Blue	Yellow
Number of Pixels – 2017	595,129	586,865	1,093,926
2019 Number of pixels vs NDVI			
Number of Pixels – 2019	676,859	828,989	745,563

Figure 3. The vegetation cover density across Malta and Gozo in March 2019



Measuring the arable and rural land loss (March 2017-March 2019).

In the next part of the study, a bi-temporal analysis was carried out to show the changes which occurred from 2017 to 2019 in the classification categories. A formula based on image and vegetation differencing was used to assess the amount of change which occurred on land across the Islands. Software algorithms were coded and used to work out the formula, by comparing two images *dn1* and *dn2*, subtract values and add a constant value J on a band by band and pixel by pixel basis, to produce an image which represents the change between the two-time periods:

$$D_X^{n} = X^N_{op}(dn2) - X^N_{op}(dn1) + J$$

where, X^N_{op} = pixel value for the NDVI band while *o* and *p*, are representing the *x* and *y* position for each pixel. *dn1* is the 2017 Sentinel-2 image = first date; and *dn2* is the 2019 Sentinel-2 image = second date; and *J* = is an algorithmic constant to produce scaled numbers in a linear proportion from 0 to 1. The aim of such a technique is to highlight the change in each pixel attribute between the two time periods. The data for pixel change within each category from one image to another is shown in the change-detection pixel matrix for Malta and Gozo, in Tables 2 and 3.

Table 3: Vegetative Habitat loss from March 2017 to March 2019

Type of vegetation	Pixels change for Malta and Gozo from 2017 to 2019	Surface Area
High Vegetation	2151	$0.215km^2$
Mid Vegetation	2933	$0.293km^2$
Low Vegetation	3223	$0.322km^2$
TOTAL	8307	$0.830km^2$

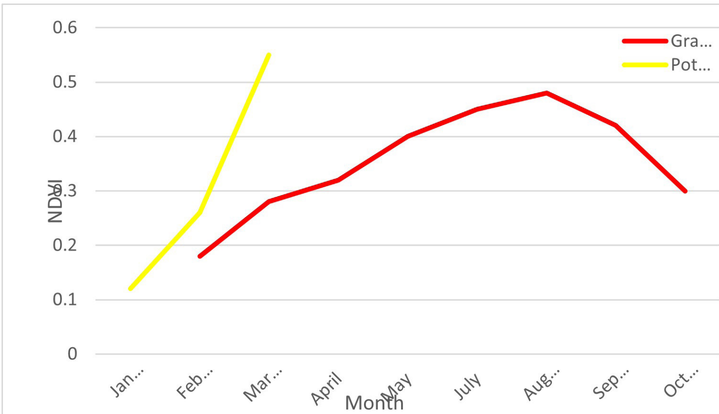
Extracting Crop Patterns

The last part of study objective was to pinpoint the fields which were used to produce two specific crops on the Maltese Islands by using Sentinel 2 datasets for the year 2020. Although crop patterns and remote sensing studies are quite popular around the world, the available solutions are not relevant to the Maltese islands due to the average small size of local fields and the 10m x 10m resolution of Sentinel 2, which is rather coarse. Thus, for this study, it was decided to extract patterns to pinpoint the geographic location of fields which were producing potatoes and grapes in 2020, rather than to map crop fields.

The growing leaf cycle of the grape trees in Malta begins in March and peaks in August. The NDVI temporal trend for grapes revealed that NDVI values for grape trees are highest in August and lowest in December and January. Despite this regular cycle, the grape plants' temporal patterns may nonetheless alter from year to year because of various agricultural techniques and other factors that are influenced by weather conditions. The potato crop on the other hand has a very interesting fast-growing cycle, which makes it unique and thus easy to distinguish from other crops. The NDVI for potatoes is relatively low in the first weeks of growth, followed by a very fast growth in a very short time when the crop reaches closer to the point of maturity. Figure 4 depicts the yearly NDVI pattern for the grape trees during the year 2020 and potato crops which were produced in the first few months of the year 2020.

To pinpoint the fields that were used for the cultivation of grapes and potatoes in 2020, a pixel-based analysis through minimum and maximum likelihood classification (MLC) was implemented, based on nine datasets. MLC root can be traced back to electrical engineering (Nilsson 1965) and makes use of a discriminant function to assign pixels to the class with the highest likelihood (Ozdarici 2012). The quantitative NDVI values for each pixel for all crops from all datasets, were stored in the database, analysed and each checked on whether the lower and higher pixel parameters, were within the threshold from negative .1 to positive .1 (−0.1 ≤ x ≤ 0.1). The ones which were found to be within the threshold and fitted the temporal pattern for grapes or potatoes were highlighted as class grapes and potatoes, while the pixels which did not fit within the temporal threshold, were highlighted as class others. A ground truthing exercise was carried out to assess the accuracy of the results obtained.

Figure 4. The yearly NDVI trend for grapes and potatoes over the Maltese islands in 2020



Results and Discussion

Vegetation cover density across the Maltese Islands

The vegetation density cover studies at this stage only measured the greenness generated by all types of land vegetation across the islands, such as crops, shrubs, trees and plants. The total number of pixels indicating the amount of vegetation for the year 2017 amounted to 595,129 pixels for low-dense vegetation; 586,865 pixels for medium dense vegetation; and 1,093,926 for high dense vegetation; a total of 2,275,920 pixels. The total number of pixels indicating the amount of vegetation for the year 2019 amounted to 676,859 pixels for low-dense vegetation; 828,989 pixels for medium dense vegetation; and 745,563 for high dense vegetation; thus, a total of 2,251,411 pixels.

The local high vegetation is characterised by mature trees, crops at mid- and end of the cycle, and dense vegetation in shrublands. Medium vegetation is characterised mainly by garigue, marquis and shrublands; while the dispersed wild plants characterise low vegetation on rocks and cliffs, garigues with minimal vegetation, small or immature trees, and crops at the early stage of their cycle. These results were verified after sampled NDVI values were compared to ground truthing analysis as listed in Table 4.

Vegetation Cover Density in 2017 vs 2019

The analysis showed that in 2019, the vegetation surface area across the islands was less dense than that of 2017. The comparison was made on a 2019 dataset which was taken in the last days of March, while the dataset for 2017 was taken in the first few days of March. These results show that there was a reduction of 24,509 pixels of vegetation through all categories. Converting this number in terms of surface area, this would equal a 2.45 km² reduction of green colour vegetation over the Islands from 2017 to 2019.

Comparing results for Malta and Gozo

Table 4: Comparing the amount of surface vegetation in Malta and Gozo for 2017 and 2019

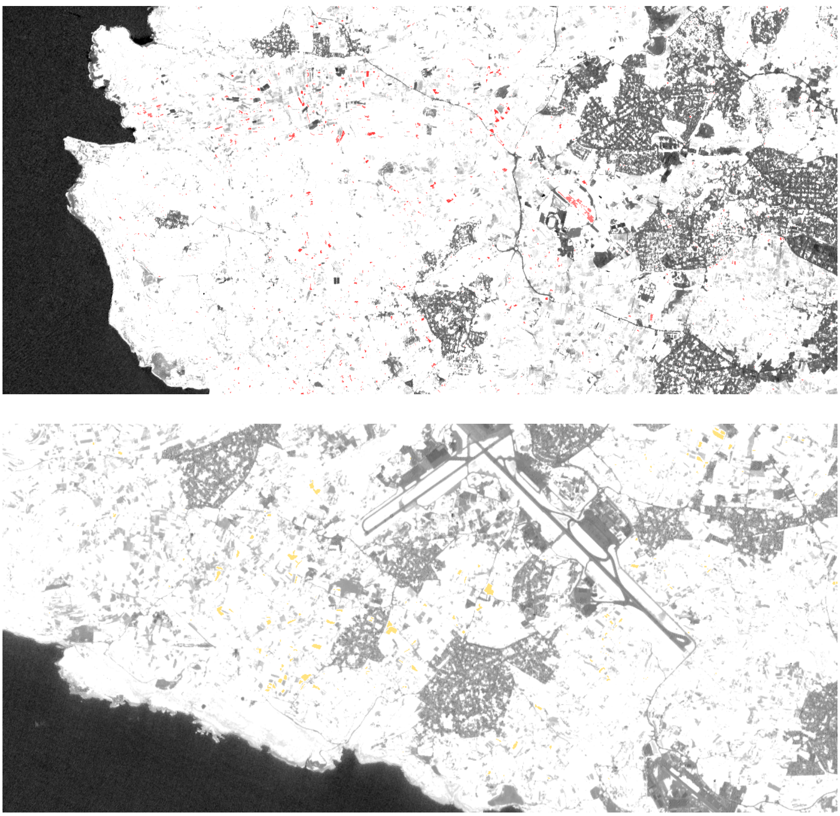
		Vegetation	Low	Medium	High	Total
2017	Malta	Surface Area in Km²	48	47	75	
		% of land	19.50%	19.10%	30.50%	69.10%
	Gozo	Surface Area in Km²	9.7	11	34	
		% of land	14.50%	16.40%	50.75%	81.65%
2019	Malta	Surface Area in Km²	51.9	60.8	56	
		% of land	21.00%	24.70%	22.76%	68.46%
	Gozo	Surface Area in Km²	13.8	21.9	18	
		% of land	20.59%	32.68%	26.86%	80.13%

Dividing the results obtained from Table 4, to get a better picture on the distribution loss for the 2 main islands, Malta and Gozo, results showed that when reducing the percentage numbers of 2019 from 2017, the reduction was dispersed across both islands, with Gozo recording the highest percentage of vegetation cover loss: a 1.52% reduction, and Malta registering a 0.64% decrease.

Crop Patterns

The MLC pixel analysis results showed that 7,291 pixels were classified as class for grapes and 31710 were classified as class for potatoes. It should be noted that the scope of this exercise was to pinpoint fields which were producing the two crops, and not to extract the surface area size. Figure 5a shows the grape fields which are in the north-west of Malta and the potato fields in the southern region.

Figure 5a. Grape Fields in the Northwest of the islands 2020 and Figure 5b potatoes field in the South east of the Islands 2020



Validation and Ground Truthing

Classification accuracy assessment is important to check for individual classification if the resulting data are to be useful in change detection analysis (Owojori 2005). A classification accuracy assessment for the foundation study and change detection was performed based on 270 and 150 random points consecutively and were identified by using a stratified random method. The 270 + 150 NDVI values for both testing procedures were than compared to the ground truth, by doing on-site view inspection. The ground truth point's data and the classification results were compared and statistically analysed using error matrices as shown in Tables 5 and 6.

Table 5: Accuracy results for the NDVI grading

Variables	No of Samples	User Accuracy
Water	50	100%
Bare land	60	98%
Soil	40	93%
Shrubs	30	95%
Trees	40	87%
Crops at final stages	50	95%
Total	270	
Average Total		94.7%

Table 6. Accuracy Results for Classification:

Variables	No of Samples	User Accuracy
Low Vegetation	50	94%
Medium Vegetation	50	98%
High Vegetation	50	98%
Total	150	
Average Total		96.6%

Another second accuracy assessment in this study was done by using historical high-resolution google imagery obtained from Google Earth Pro (Google Inc., Mountain View, CA, USA). Two google images captured in 2017 and 2019 were used to carry out the accuracy validation for the land usage and land cover of both respective years. The value of overall accuracy again was greater than 95%.

Testing the Crop Patterns

Since the scope of the last study was to pinpoint the fields accurately rather than to work out the surface area, it was expected to find a high percentage of true values for the pinpoint classification technique, but a much lower percentage for a correct number of pixels in sampling points.

Classification Accuracy: 5 samples for classes grapes and potatoes were selected and 15 classes for class others (Tables 7 and 8).

Table 7: Classification Ground Truthing

Classes	**Sample Points**	**Ground Truth Results**	**% Accuracy**
Grapes	5	5	100
Potatoes	5	5	100
Others	15	15	100

Pixel count accuracy for grapes: Two site locations were selected to compare grape pixels selected numbers. The first Area is called ‘Il-Marnisi’ and is located at Marsaxlokk Malta, Latitude 35.846424, Longitude 14.532519, This site is one of the estates which belong to Marsovin Wineries. The second site is called ‘Meridiana Vineyard’ which forms part of the Meridiana Wine Estates and is located at Ta‘Qali, Latitude 35.898401 and Longitude 14.419753.

Out of the 7,291 obtained class grape pixels, 676 pixels were located inside the selected regions at the Marnisi and Meridiana sites, with 330 pixels at Marnisi and 346 at Meridiana, as shown in Figure 5a in red and 5b in yellow. The total amount of the real ground truth pixels, which truly reflects the total area used for grape cultivation, amounts to 648 pixels for the Marnisi site, while 1,768 pixels for the Meridiana site. The classifier only detected 38% of the ground truth total pixels for both crop classes but at a 100% class selection accuracy.

Table 8. Obtained Pixel number vs ground truth representation

Site	Obtained number of pixels	Ground Truth Pixels	% Accuracy
Marnisi	330	648	50.9
Meridiana	346	1768	19.57

Recommendations

This work provided analytical proof that NDVI data modelling tools may be developed and applied with Sentinel-2 datasets of the Maltese islands, to classify land cover, analyze land surface changes, and identify fields with specific crops.

The challenges in this study were unique due to the limited number of resources on the subject that were available for the Maltese islands. The author created software libraries to derive the findings of this study. Available off-the shelf software libraries which are embedded in the Sentinel 2 toolbox were also tested, however the results obtained were of an inferior quality for land changes and patterns and not useful to pinpoint crop patterns over the Maltese Islands. The Sentinel 2 toolbox with embedded libraries were also tested, but the outcomes were less precise, for NDVI changes in land patterns, and were not able to pinpoint any crops when used with Maltese islands datasets.

The author intends to continue improving the developed tools and add new datasets, divide the Maltese Islands into smaller geographic units to increase classification accuracy and resolution, add more crop patterns, and create new software to improve crop pattern pixel representation accuracy.

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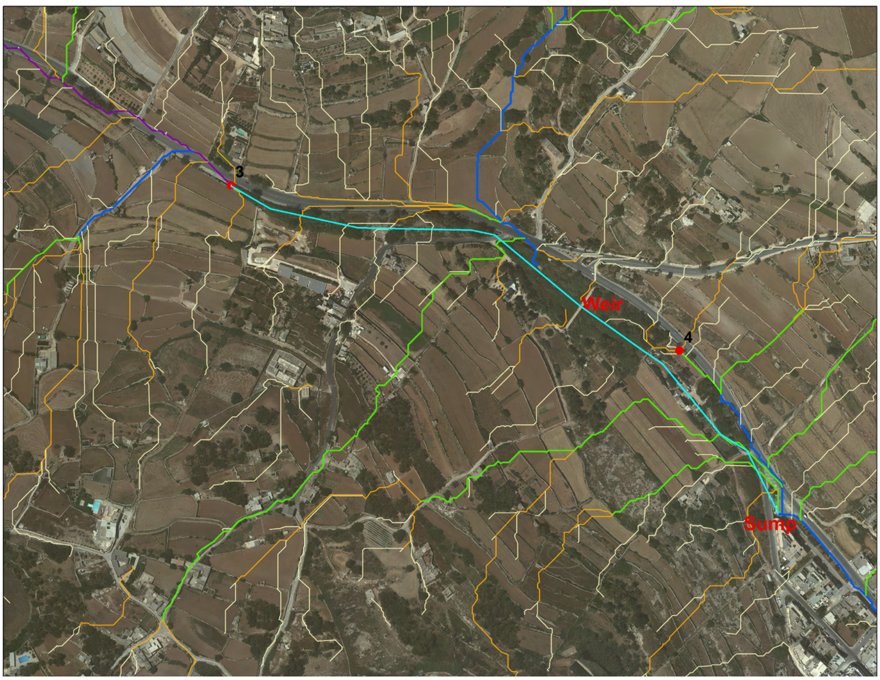
Pivot IV

Ancillary Domains



Hydrological Map Marsaskala

CHAPTER 17

Mitigation of DoS / DDoS Attacks In Sensor IoT Networks Through The Moving Target Defence (MTD) Strategy

David Spiteri

Keywords

IoT, DoS, DDoS, Security, smart sensors

Project Aim

The aim of this project was: (1) to propose a solution with the ability to mitigate DoS / DDoS attacks in any sensory / IoT network architecture while still being able to record spatial data generated by the targeted geolocated sensors, (2) to simulate an operational and functional technical solution.

Introduction

Literature

DoS / DDoS attacks

The goal of DoS / DDoS can be twofold. It can either be an attack on its own, to disrupt services by flooding a network / system and bring the latter down to an unusable state, or, as more recently being used, to cover up a much larger attack (Newman, 2019). The main difference between a DoS and a DDoS attack is that a DoS attack is mainly a one-to-one attack, while DDoS is a many-to-one attack, thus DDoS attacks are much more intense, serious, and destructive. Bhardwaj, Mangat and Vig (2020) state that the growth in productivity of highly vulnerable IoT devices (sensors) is increasing at an alarming rate.

Although DoS / DDoS mitigations and countermeasures have been studied for a long time, (Lotlikar et al., 2018) states that such attacks are on a massive increase. The authors put the blame on the rapid growth of the Internet over the last two decades. Yet, one can also add that the increase in computing performance and the rise of 'easy to hack and compromise' embedded smart devices in IoT (Galeano-Brajones et al., 2020), could also lead to such attacks. (Bhardwaj, Mangat and Vig, 2020) continues that the growth in productivity of highly vulnerable IoT devices is increasing at an alarming rate.

MTD

Originally a military defence tactic, according to Gillin (2017), MTD theory was introduced into the Cyber-Security domain by the U.S. Department of Homeland Security through a funded project aimed to develop dynamic capabilities that shift the attack surface and make it more difficult for attackers to achieve their final aim of an attack. Edward (no date) states that MTD's starting point is the assumption that perfect security is unattainable and that all systems are compromised, thus MTD should focus on enabling systems to continue their safe operations in a compromised environment. Cho et al (2020) state that MTD can be adopted into either a proactive or reactive approach based on three (3) key design principles: What to move, How to move, and When to move.

Successful case studies and related works of practical utilisation of MTD, generally fall into two (2) distinct categories:

a) Dynamicity – Most of the studies fall under this method, whereby network addresses and other resources are shuffled to create confusion to any threat actor. Yet according to Zhou et al. (2020), despite increasing security, such dynamicity causes a heavy burden on the system and its administrators due to the continuous shuffling of resources. Cho et al. (2020) further elaborates that one must develop a strategy of frequency triggering to solve the heavy burden issue.

b) False Reality – Few other studies employ a false reality method to confuse an attacker. Such a method makes use of a decoy to direct the attacker towards it rather than the intended system. Park et al (2020) found that such methods employ minimal system overheads.

Methodology

This project employed both qualitative and quantitative methodologies to reach the objective.

Qualitative Approach

Qualitative methodology founded the basis of this project. The research conducted, was produced in the Literature review section, and presented according to common factors found within them. A hypothesis was also qualitatively developed through discussing observed characteristics of MTD derived from the literature review, which can complement the characteristics and attributes of an IoT network scenario.

Quantitative Approach

A simulation of the proposed system was done to test the hypothesis. This simulation was performed in a controlled lab environment. Quantification of the effectiveness of the solution was then presented through graphs and tables which show results of how the system handled the simulated attack based upon the extent of the attack.

Hypothesis Formulation

Characteristics

Although in many studies MTD is used as the only security solution, this is very difficult to be introduced in already established scenarios where layered security strategies are already in place. Layered strategies employ various security controls that help slowing down the attack until it is detected by the monitoring systems and a quick mitigation solution is utilised to stop or block the attack. Thus, it would be more beneficial if MTD is incorporated within a single comprehensive integrated security framework. This would introduce advantages derived from MTD's unique characteristics, while also covering other unguarded aspects of MTD.

Research in MTD shows that the main characteristics of this theory include an increase of difficulty for an attacker to either launch an attack or to be successful in harming the system, deception, dynamicity, a movement concept, and an offensive approach to defend the underlying network. Moreover, these characteristics can be employed in either a pro-active or else a reactive approach.

Hypothesis Foundation

The hypothesis was formulated on employing MTD into an already established network architecture and based upon the technique used by Debray et al. (2020) whereby the attacker is moved towards a false machine and away from the real target, and the key design principles of Cho et al (2020).

What to move?

Since the starting point of MTD is the assumption that the system is already compromised, it is being assumed that sensors at the Edge are already compromised, also since these are the most vulnerable devices in the system. Thus, the attack surface from this point of view is either the immediate storage and processing layer or the central core storage layer. In view of this, any movement should only be involved in the identified attack surface

When to move?

Due to the strains that dynamic changes bring on a system, for a proactive approach, a reactive approach would be more ideal. Moreover, a dormant attacker at the Edge layer, scanning the network, could detect the dynamic changes done from time to time, and wait until the changes are mapped out. This will not solve the issue, but rather lengthen the time until the attack happens. A reactive approach on the other hand is not detected, at least before the actual attack happens, and such approach triggers a change once the attack is detected.

How to move?

In a traditional network setup, where no central core intelligent system exists, an attack can be re-directed onto a false target by altering traffic at layer 2 of the Open Systems Interconnection (OSI) model. Since a change in the network switches Address Resolution Protocol (ARP) table will redirect all the traffic towards the false machine, it would cause the legitimate traffic from the other devices to be lost. Thus, changes in ARP tables should happen at the Edge layer. This hybrid MTD strategy will cause a reactive change at the attack surface by shuffling the MAC address and setting a false target with the same MAC address. From the system's perspective, this strategy will put a false target between the attacker and the attack surface so that it defends the target through a re-active shuffle of the target's MAC address. Using such a strategy will remove the need to introduce pro-active dynamic movement at the attack surface, but rather causing a reactive minimal movement (in view that no IP addresses are changed) unknowingly to the attacker. The false target must be put as close to the attacking machine as possible. This will make sure that network flooding stays to a minimum.

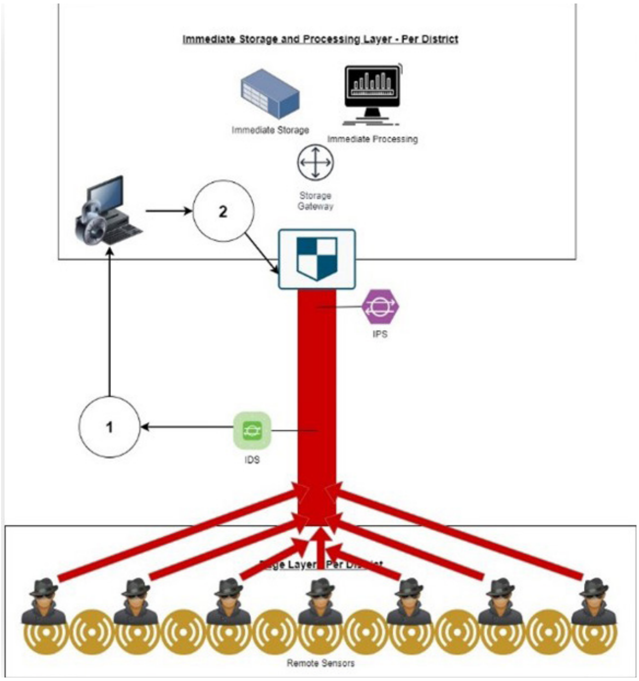
Design

Figure 1 illustrates a graphical representation of the Hypothesis design, based upon the discussions presented in this chapter. This illustration shows numbered steps 1 and 2.

Step 1 – IDS detects the attack and relays the information to another system.

Step 2 – Upon information that an attack is happening, the system triggers a shielding machine to substitute the attack surface. This will also generate a change in direction of the traffic coming from the attacking machines, whereby it now travels towards the "Shield" machine, leaving the path towards the original attack surface, free of any flooding. The Shielding system would also be capable of conserving any IoT data sent by the attacking sensor.

Figure 1: High Level Hypothesis Design



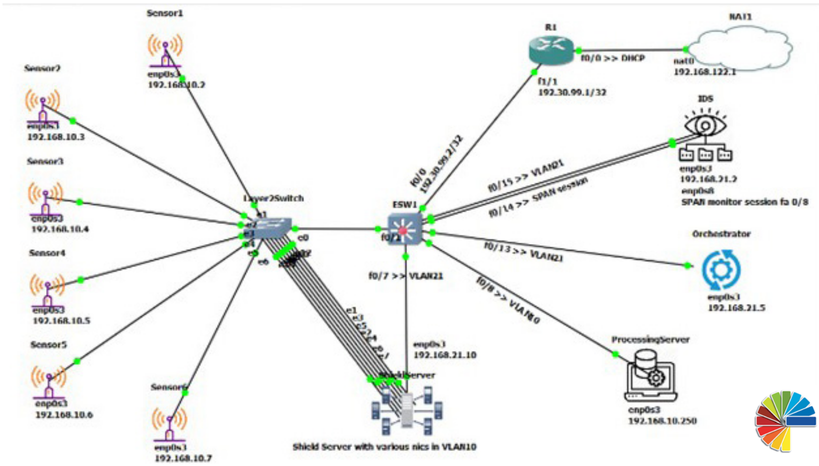
Results

Simulation and Testing

Simulation

A simulated solution was tested in a controlled lab environment as per Figure 2. This test included 6 sensors sending traffic data (simulated motor traffic data which included the sensor name, date, time, current and average speed, and the longitudes and latitudes) to a core server that processes and saves the received data. An Intrusion Detection Server (IDS) was configured to detect any unusual data traffic flow, and if such is detected, it sends a signal to an Orchestration server. This Orchestration server was programmed to control the security solution by switching on network cards on the Shield server and directing attacks onto this Shield server by swapping the MAC address of the central core server with that of the new NIC and vice versa. The mitigation solution was also programmed to record the results and the time taken to mitigate each attack.

Figure 2: Simulation Setup for Solution



Testing

Different tests were conducted to quantitatively test the mitigation solution.

Baseline Tests – Two (2) different tests were run to have a baseline of the scenario without the mitigation solution so that results of the solution can be compared with them. Baseline Test 1 analysed the data transmission statistics under normal circumstances with spatial data being sent every 2 seconds. Baseline Test 2 analysed data transmission statistics during a DDoS attack from every sensor.

Mitigation Tests – Four (4) tests, tested the mitigation solution under different scenarios. Tests 1 and 2 tested the mitigation solution in a scenario whereby an attacker started a DDoS attack from each sensor, in a sequential order, 1 minute apart. Tests 3 and 4 tested the mitigation solution in a scenario whereby an attacker started a DDoS attack from all sensors en masse. Tests 2 and 4 included a re-try of the attack which simulated an attacker that detected the accomplishments of the mitigation solution.

The following were the key results of the project:

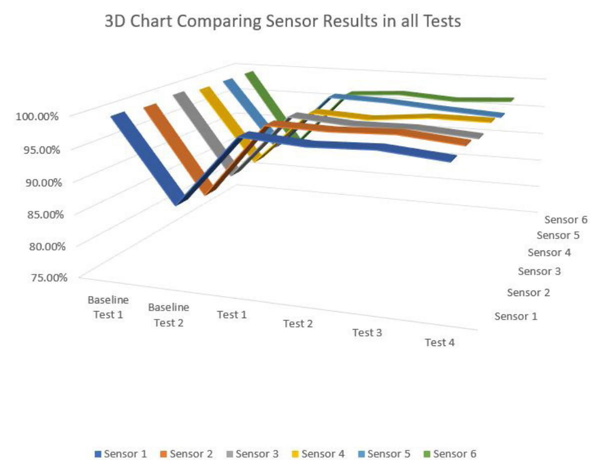
- While other DoS / DDoS mitigation solutions solve the attacks by blocking all incoming traffic, this mitigation solution scored a 100% success rate in mitigating all attacks as per Figure 3 while also scoring very good results in the general availability of spatial data during attacks as shown in Figure 4.

- Figure 4 depicts a 20% drop in spatial data availability during Baseline Test 2 where attacks were not mitigated. This means that the MTD solution brought the availability of spatial data transmission to the 95% range.
- Another successful aspect of the solution in favour of spatial data availability is the fact that transmitted data from the attacking sensors was still recorded and saved on the Shield server. This makes it possible to filter out and remove the unwanted bogus data that an attacker might inject to perform the attack.
- Since it is a common aspect of IoT networks to compare and analyse past gathered spatial data, the above results also mean that the solution was effective in increasing the integrity of any future studies and analyses, in view that a successful analysis and comparison between past and current scenarios can be performed.

Figure 3: Success Rate of Mitigation Solution per Test

Test No.	No. of Sensors to Move	No. of Sensors Moved	Success %age
Test 1	6	6	100%
Test 2	12	12	100%
Test 3	6	6	100%
Test 4	12	12	100%

Figure 4: 3D Graph Comparing Sensor Results in all Tests



Recommendations

Key recommendations of this study are:

This MTD solution should be implemented at every distinct IoT setup which forms part of a larger IoT ecosystem. This makes each distinct solution tailored to the needs of the setup being employed in. Moreover, such a setup helps reduce unwanted harmful traffic flows at the upper architectural layer of an IoT ecosystem. Such a design will also aid in the scalability factor, should the need to scale further arises.

The shielding feature of the solution should be placed as close to the sensors as possible, to protect the inner / core network layer from unwanted harmful traffic flows.

The solution presented allows spatial data from attacking sensors to still be captured and stored while shielding the attack. As a future enhancement that compliments the solution, a system should be studied which can further process and filter the data to distinguish through the legitimate data from the fake data that an attacker might inject.

As a final note, the solution should be tested in proper real-life environments once all the previous future work has been completed. Such tests would further elaborate on the solution functionality and how the generated traffic from attacks could affect the solution. Results can also be compared with other DDoS mitigation solutions to further analyse the solution's achievements.

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CHAPTER 18

Maltese Stakeholder Involvement in the Nation's Planning System

Francesca Gatt

Keywords

Stakeholder involvement, spatial data, spatial analysis, statutory consultees, public participation, citizens' juries, Malta, local councils, project lifecycle

Project Aim

The aims of this project were:

1. to investigate whether methods of early identification and prioritisation of stakeholders may improve stakeholder involvement in the planning process;
2. to assess stakeholder attributes of imposition of will on other stakeholders (power), importance of role for the good of society (legitimacy) and the degree of attention given to other stakeholders' knowledge (urgency), needs and input in Maltese urban planning;
3. to analyse the effectiveness of an integrated GIS system for the purposes of encouraging stakeholder involvement in Malta's planning system;
4. to analyse ways how to improve public participation during the planning process; and
5. to assess the applicability of citizens' juries to improve stakeholder participation in the planning processes for major projects.

Introduction

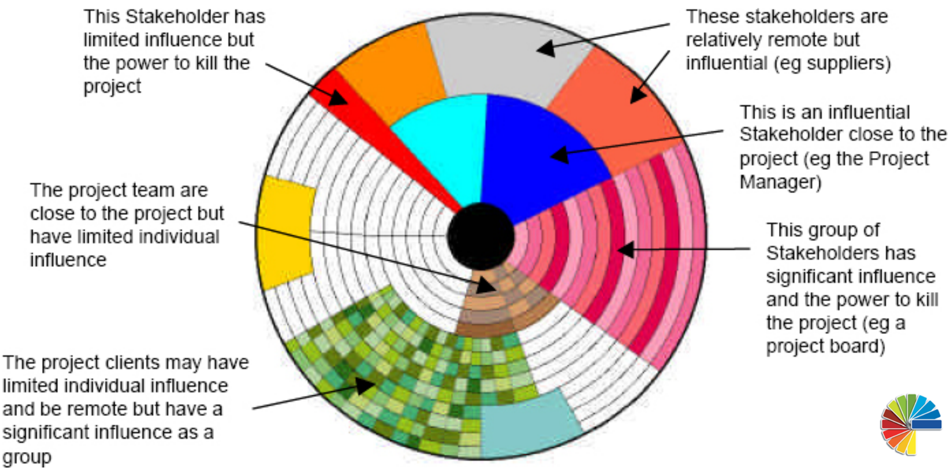
Bingham et al. (2005) analysed stakeholder improvement in public administration and Government planning projects, and state that to ensure proper practices and processes for stakeholder and citizen participation in the work of Government, "we must understand the role of humankind—the citizens, stakeholders, and public administrators who are the tool makers and tool users". Successful stakeholder engagement relies on proper stakeholder identification and analysis. Kennon et al. (2009) emphasise this notion through the five steps of stakeholder analysis, as follows:

- identification of stakeholders;
- understanding and management of these stakeholders;

- setting of goals;
- identification of cost of engagement; and
- evaluation of Analysis.

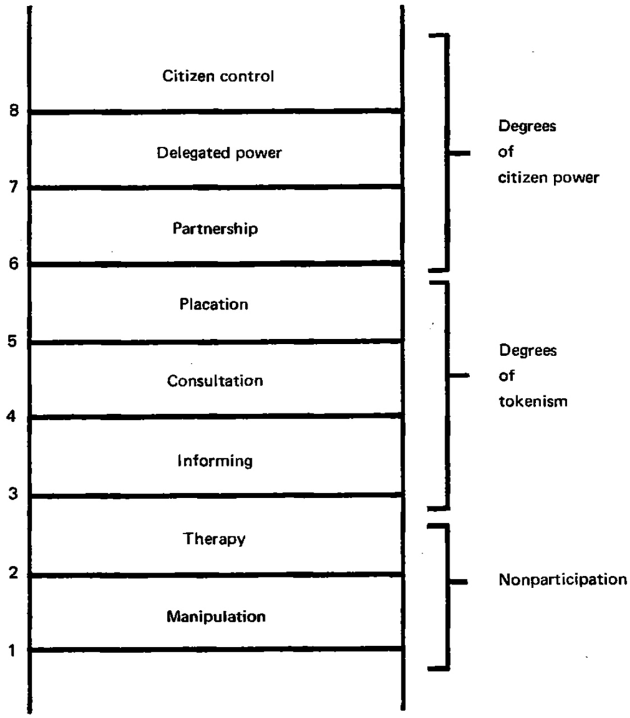
Scholars have sought different ways of illustrating stakeholder relationships to identify and prioritise their importance in policy-making and urban projects. Bourne (2006) analysed the prioritisation of a project's key stakeholders through the formation of a 'Stakeholder Circle' methodology (reference to Figure 1). Arnstein (1969) analysed citizen involvement in planning processes in the United States throughout the 1960's and 1970's. She proposed a "ladder of participation" to illustrate the types of stakeholder participation with respect to the general public, as shown in Figure 2.

Figure 1: Stakeholder Circle Methodology



Source: Bourne (2006)

Figure 2: The Eight Rungs on a Ladder of Citizen Participation as illustrated by Arnstein



Source: Arnstein (1969)

Soma et al. (2018) analysed the role of stakeholders in society with respect to their contributions towards increased urban sustainability. The researchers analysed science-based initiatives, stakeholder-based initiatives and government-based initiatives as impacting the roles of stakeholders in urban policies and projects and motivating their participation in such endeavours.

Science-based initiatives for motivating stakeholders to collaborate in urban policymaking and projects are described by Soma et al. (2018) as "theories, methods, frameworks, models, indicators, and so forth, which are developed by researchers who need information by stakeholders in their research approach" in order to encourage transmission of information in a transparent manner. Such initiatives include participatory geo -spatial technologies such as that explored by Stauskis (2014) in the study of virtual reality and spatial modelling of Missionaries Park at Vilnius, Lithuania as a tool for participatory urban planning. The research team built a 3D model of the site and provided gaming features including moving characters, interaction with environmental elements and possibility of introducing hard and soft landscaping features within the model. Residents were invited to utilise the gaming tool to alter the park layout for two different scenarios: design for family recreation activities and design for recreation of groups of friends.

The resultant designs were presented to urban planners and policymakers after the community involvement phase. Following the success of this exercise, Stauskis (2014) states that "virtual reality models allow the citizens to understand spatial and temporal processes of design; they encourage communication and comprehend planning proposals". The researcher concludes that ICT technology is a vital tool for actively motivating the public to participate in the design of projects and urban policies, together with stimulating collaboration with governmental stakeholders and urban planners.

Stakeholder-based initiatives include access to sharing of knowledge. Soma et al. (2018) found that "learning opportunities are shown to influence stakeholder perceptions" through the analysis of various case studies including those on mobility options in Granada, Spain (Valenzuela-Montes et al., 2016) and waste management facilities in Naples (Hornsby et al., 2017). With respect to government-based initiatives, the researchers state that "strategies to enhance trust among stakeholders, accountability of government and to facilitate co-production of knowledge to inform shared decision-making is one of the key initiatives". They also recommend integrated management and coordination between stakeholders. Reference is made to studies by Arsenio et al., 2016, who analysed the effectiveness of Sustainable Urban Mobility Plans (SUMP) throughout the European Union and specifically,in forty cities across Portugal, in order to replace traditional planning policies solely based on motorized road traffic/infrastructure provision.

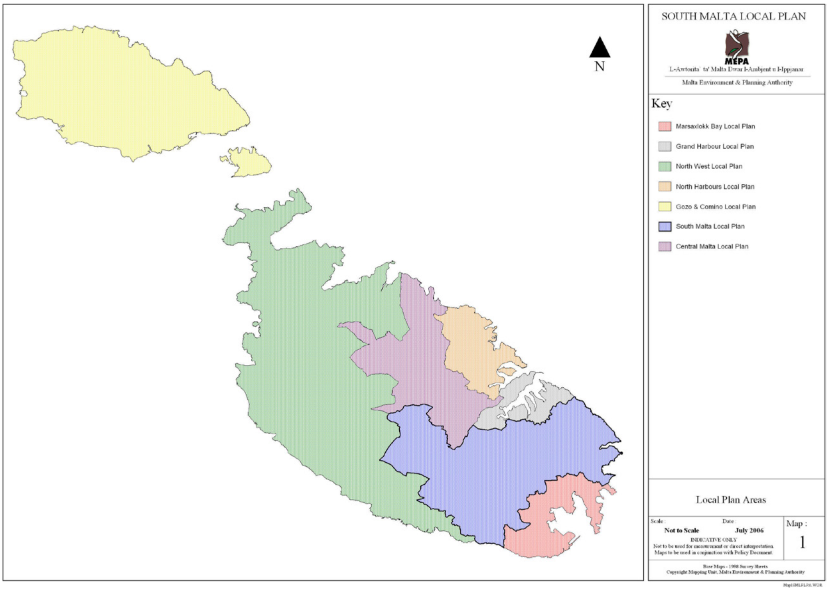
With respect to Malta's planning system, the public is invited to discuss new policies and action plans through adverts in the Government Gazette. The public is also given a one-month time frame to object to or comment on any planning proposal from the time of publishing of the proposal in the Government Gazette. Conrad et al. (2011) conducted a participatory assessment of public participation in planning in the Maltese Islands by assessing public views on the concept of landscape changes due to planning in Gozo and the implementation of the European Landscape Convention of fostering appreciation and value of the European landscape across the bloc. Surveys were conducted electronically, and results show that "substantial knowledge of, and interest in, landscape matters was apparent amongst the public, and there was also significant consensus across different respondent groups". It was also noted that the following hindered the public involvement exercise (Conrad et al. 2011, p. 169):

- Limited awareness and linguistic confusion;
- Dissatisfaction with spatial planning mechanisms; and
- A perceived lack of public influence on decision-making.

In terms of stakeholder inclusivity, ten statutory authorities are automatically consulted on each planning development proposal received by the Planning Authority. These are listed in schedule 3 of L.N. 162/16 and include the Superintendence of Cultural Heritage, the Environment and Resources Authority and the Commission for the Rights of Persons with Disability among others. Their expertise contributes to the overall success of the project, and their concerns can also influence the decision of the Planning Authority with respect to granting or refusing development permission. However, there is unwillingness of authorities to share and make available their knowledge with each other in spatial planning terms. The Planning Authority has an online Geoserver which is freely available and shows all planning applications, permissions, and several constraints covering the Maltese Islands which is divided into areas covered by seven Local Plans. These divisions are shown graphically in Figure 3.

The Planning Authority Geoserver is available for the general public to make use of in terms of spatial tools and aims to increase participation in terms of acquired knowledge on sites, proposals and geomatic data which may be used when discussing spatial planning projects and policies. However, the PA Geoserver does not contain certain constraints and data gathered by government entities, which could be very useful to formulate policies and contribute to broad-ranging assessment of planning proposals.

Figure 3: Local Plan areas making up the Maltese Islands

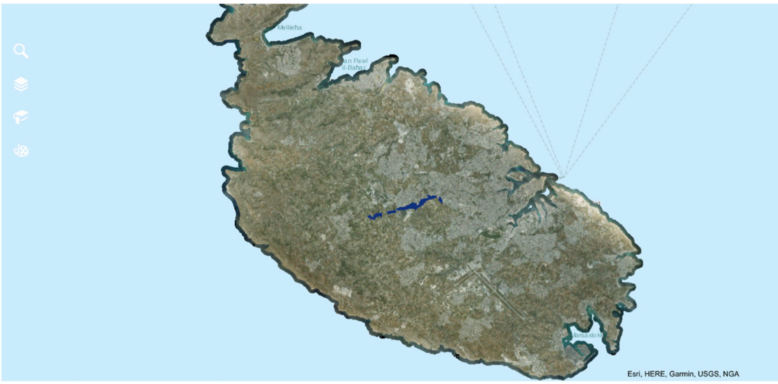


Source: www.pa.org.mt

A study presented by Cassar et al. (2010) assessed the functioning of public participation mechanisms based on the perspectives of members of the public, planners and policy makers. The views of these stakeholders on the participation process, the extent to which participatory practices meet their expectations, and ways in which these can be made more effective were analysed. The researchers note that “there needs to be an ingrained culture of evaluation, which includes the identification of indicators for ongoing monitoring, and a transparent framework for any form of public engagement” specifying the extents and mechanisms of how the public should be involved in such decision-making, especially through the use of spatial planning tools.

Yin (2009) describes case study research as a preferred design method when research questions involve ‘how’ and ‘why’, when the researcher has limited control over events but wishes to analyse these in terms of current social aspects, and when the research focus is “on a contemporary phenomenon within a real-life context”. This study sought to address both ‘how’ and ‘why’ types of research questions, in terms of how stakeholder identification and prioritisation is currently being conducted, and why is there such controversy among stakeholders surrounding certain large scale infrastructural works in Malta, including the Central Link project.

Figure 4: Aerial view of Malta showing the extent of the Central Link project (marked in blue)



Source: Planning Authority Geoserver (https://pamapserver.pa.org.mt/

Methodology

With respect to methodology, a qualitative approach was used to analyse the extent of stakeholder involvement and stakeholder identification, prioritisation and assessment of attributes with respect to Malta's planning system. This approach was also utilised to study the effectiveness of an integrated GIS system for the purposes of encouraging stakeholder involvement in Malta's planning system. Structured interviews on a one-on-one basis with participants were utilised as the main research tool in this study. These interviews presented the participants with an opportunity for open commentary based on the topics being discussed. The Central Link project extents as shown in Figure 4 and as extracted from the PA's Geoserver was presented to participants to discuss the topics outlined below in the context of the Central Link project:

Identification of stakeholders:

- Methods of identification and prioritisation;
- Clarification of roles of specific stakeholders.

Assessment of stakeholder attributes:

- Assessment of imposition of will of that particular stakeholder on other stakeholders;
- Ranking of importance of role;
- Assessment of attention given to other stakeholders' knowledge, needs and input;
- Analysis of the effectiveness of an integrated GIS system for the purposes of encouraging stakeholder involvement in Malta's planning system.

Public Participation:

- Elements deemed critical for effective functioning of public participation;
- Rating of current public participation in urban planning applications and projects;
- Factors which encourage and discourage public participation in Malta; and
- Any aspects which could be employed to render public participation more effective for planners and more satisfying for the public, such as more user-friendly tools to utilise the current Planning Authority Geoserver when viewing proposals online.

Citizens' Juries:

- Effectiveness of engagement of the public through such juries;
- Foreseen constraints if such juries are held.

The transcribed data collected from interviews was organised in tabular format in two stages. The first stage analysed experiences and recommendations of two 'groups' of stakeholders with respect to the identified themes: one group representing the general public (residents and non-governmental organisations) and the other group representing planning professionals and national consultative bodies with official affiliation to environmental, planning, cultural heritage and transport agencies with respect to the Central Link project. This is a similar format to that adopted by Cassar et al. (2011). The second stage analysed findings across the two groups by comparing the recurring topics present in each set of findings.

Results

Key results of this project study include the following:

- Identification and prioritisation of stakeholders early in the project lifecycle is vital to identify constraints and issues which may hinder the spatial planning process. The public should be prioritised through the presence of Local Council representatives in such discussions.
- Roundtable discussions between stakeholders are important as these offer opportunities for debate and have proven to be effective among statutory

stakeholders of the Central Link project. Such roundtable discussions are currently not part of the initial planning process prior to official consultations forming part of the legislative planning process.

- Stakeholder involvement would greatly benefit from an integrated GIS system where information could be shared with every entity included in the assessment of spatial planning. However, privacy considerations need to be made, and all information should be made available to the public, as per recommendations by the interviewees.
- An integrated GIS system should strive to include all possible data from government stakeholders, such as the Superintendence of Cultural Heritage and Transport Malta. From interviews carried out with representatives of these entities, such data is available for use and is seen as an advantageous strategy to increase the availability and power of geomatic tools to assess large scale infrastructure projects, such as the Central Link project.
- With respect to stakeholder attributes and the attribute of power, findings from this study show that government agencies applying for road widening projects strongly impose their will on land use planning. Whilst conceding to amend certain design details through stakeholder discussions, are not willing to backtrack on a project concept at the initial stages. Regarding the attribute of legitimacy, social benefits from stakeholders are not being felt in land use planning, and the public's perception of statutory consultees in terms of legitimacy is that of being merely procedural. The Planning Authority's Geoserver tool was praised by interviewees representing the public in terms of being user-friendly, and the range of information it offered. However, it was viewed as simply a geomatic tool rather than a source of encouragement for the public to engage in stakeholder discussions regarding infrastructural projects. Regarding the attribute of urgency, all interviewees agreed that stakeholder and public engagement in the earliest possible stages of the project lifecycle contributes to effective stakeholder relationships and communication.
- Malta's Local Councils should be given more legislative spatial planning rights regarding projects taking place in their communities.
- There was a consensus among interviewees that citizens' juries are not practical to discuss and decide upon land use project concepts in Malta for the following reasons:
- Since Malta is a very small country, individuals are directly influenced by one another and there can be a lack of rationalisation in this regard; and
- Cultural influences whereby the country's bi-party political system dictates the public perception of what is acceptable in terms of land use planning.

Recommendations

Key recommendations for policy and operational change include the following:

- Analysis of roundtable discussions among stakeholders at the early stages of the project lifecycle and how these can be formulated, encouraged and facilitated;
- Encouraging the use of an integrated GIS system through the sharing of information and making this available to stakeholders and the public; and
- Stakeholder participation in discussion of land use policies and the consideration of citizens' juries in deciding on such policies.

Key recommendations for further research are:

- Analysing Maltese stakeholder involvement in the nation's planning system by considering major projects proposed by private investors, rather than considering government projects such as the Central Link project; and
- Investigation of increased influence and legislative planning rights given to Maltese Local Councils representing local communities, to strengthen and motivate the public as an effective stakeholder.

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CHAPTER 19

Review of Classification Techniques Applied on HAR Against Existing Datasets and an Enhanced Dataset

Jonathan Camilleri

Keywords

HAR, Activity Recognition, Spatial Data Manipulation, Machine Learning, Dataset, Classification, PEM

Project Aim

The aim of this project was to determine the replicability and reproducibility of various HAR classification techniques across multiple datasets, including the new PEM dataset.

Introduction

Wearable sensors have become more common in consumer electronics, resulting in a wealth of data generated by the consumers, the study of which is called Pervasive Computing. HAR is an essential component of this field. With this, identification and classification of activities can be performed on a wide variety of activities, including walking, running, falling and sitting. Nonetheless, through HAR, even more complex activities can be recognised, such as playing video games, watching TV and vacuuming. A well labelled, time-series dataset is required to train the algorithm to identify or classify the activity being performed at any given time. Feature extraction of the raw data is conducted and used to train the model, thereby identifying and recognising the activity from the raw sensor data (Lara and Labrador, 2012).

Wearable sensors are unobtrusive and provide an accurate reading of the user's activities such as location, position and speed, among others at a relatively low cost. The raw data from these sensors can then be used to train machine learning algorithms which would in term be able to identify and classify the users' activities based on the raw sensor data (Bulling et al., 2014). The generation of activities is popularly used in fitness trackers to automatically determine the user's exercise. Further uses are in the field of patient tracking, whereby sensors can be used to allow for more patient independence and easier care, as the caretaker would be able to allow the patients to wander around and be automatically summoned if the patient is confused or is unable to move after having fallen.

Smartphones offer a very effective and easy solution to ADL data collection methods, a limitation of using mobile phones is that the sensors embedded in the smartphone are shared among several applications and may cause some issues with data collection (Anguita et al., 2012).

HAR Data Collection and Processing Techniques

There are several techniques pertaining to data collection and implementation of algorithms regarding HAR. Activity Recognition is done through recognition and learning algorithms; the algorithms and data processing techniques used to identify the activity is also dependent on the method of data collection used and which technique was adopted (Bulling et al., 2014). In Machine Learning (ML), two datasets are required: a training set and the testing set. The training set is a small subset of the data which is manually labelled and analysed. This training set is used by the ML algorithm to learn the classification method and to be able to classify the remaining data (Lara and Labrador, 2012).

Pervasive Electronic Monitoring (PEM) is an ongoing project which focuses on collecting a dataset that simulates the actions performed by Patients with Dementia with the aim of creating a framework that would improve the PEM capabilities. These activities are tracked using a combination of wearable sensors and smartphone devices. In this project, the dataset collected mainly covers the ADL that are often portrayed by Dementia patients such as wandering around, walking with purpose and even zigzagging (THINK Magazine Science, 2019).

Machine Learning

A Support Vector Machine (SVM) uses a Linear Model for classification; the basis of the algorithm is to create a hyperline or hyperplane to separate the data into classes. An SVM processes non-linear data by adding dimensions to the data (Pupale, 2019)(tec, nd). The Decision Tree (DT), is a tree-like structure with conditional control statements. The branches in the tree represent decision making steps where in every branch is an outcome and the nodes on each branch represent the rules for classification. The Multi-Layer Perceptron (MLP) is the classic type of feed-forward Neural Network. It comprises multiple neurons with an input, hidden and output layers where the perceptrons are connected to each other. The MLP is ideal for tabular data and other types of data that can be converted into a singular row in order to be consumed by the MLP. The Multi-Nominal Logistic Regression (LR) algorithm is used to create predictions for outcomes based on a dependent variable and created from independent variables. It uses probability to determine which label is more probable to fit given the scenario.

The K-Nearest Neighbour (KNN) is a supervised Machine Learning algorithm which can be used for both classification and regression. It assumes that similar are closer in proximity and therefore a higher K-Value leads to better stability (Harrison, 2018) (scikit, nd) (Navlani, 2018). For the Nearest Centroid Classifier (NCC), the centroid is computed during the training phase and the classification is performed by computing distance to all centroids, picking the shortest distance (scikit, nd) (Bora, 2020. The Linear Discriminant Analysis (LDA) and the Quadratic Discriminant Analysis (QDA) are supervised machine learning algorithms based on decision boundaries for separate classes. The linear boundary is always a straight line while the quadratic boundary can be curved. The LDA and QDA compute the probability of data distribution to the classes, where classes are divided into different regions according to the discriminant rules (Ghojogh et al., 2019) (Yang, 2020).

Methodology

The first phase of this research consists of replicating the studies which were conducted in research that investigated different algorithms to improve activity recognition through sensor and smartphone captured data. The aim of this exercise is to support or reject the results stated in the research papers from which the datasets were extracted.

In this phase, the datasets used included datasets from four previous studies which were made publicly available. These datasets contain the raw sensor data collected in each respective study which include the spatial and context data in the native format of the sensor/s. To replicate or reproduce the techniques as used in the study, a pre-processing procedure is required in order to filter out any noise data and establish a specific interval and overlapping in the data, which varies between the different studies. For this procedure, the research papers were used as a guide. In some of the research papers, the scripts used to pre-process the data were also available and therefore in such a case, the data is run through that script to pre-process the dataset whereas in other studies a specific tool is used and therefore the dataset was processed through the tool mentioned in the research paper. Nonetheless, in many of the studies used for this research, neither a script nor a tool was provided, and a custom script is written following the methodology stated in the respective research paper and Rapid Miner is used to run the dataset in question through the script.

In this phase, the results from the replication process would indicate how well the algorithms perform on the given dataset and in some cases with various feature sets. Moreover, the variation in results from those established in phase to those stated by the research paper show the success of the replication process and the robustness of the algorithm/technique used.

Assessing the Degradation of Quality

In this phase, the datasets which were used in the first phase are modified to be similar to the dataset which was collected by the PEM project. The data collected varies across the different studies. These data variables include data from different sensors where, in some studies, certain sensor data were used to build their classification models while in other studies, the same sensor data was either omitted or a different sensor is used. This also applies to the list of activity classes each study catered for.

The PEM dataset consists of data collected through an ongoing project (THINK Magazine Science, 2019) which simulates the ADL usually portrayed in a dementia patient. The dataset is gathered using the Zephyr bioharness 3 on-body sensor (accelerometer) where participants were equipped with specific gear such as knee restrictions, restricted eyesight using a darkened sunglasses and weights so as to provide a more realistic simulation of an elderly dementia patient and instructed to perform a specific activity such as going up/down the stairs and sleeping.

To conduct this study, the datasets from the previous studies were first reduced to only include data which is gathered from the accelerometer sensor to conform to the PEM dataset. Moreover, to establish the effect of data loss on the accuracy achieved by the algorithms and techniques, the activities were reduced to include some or all the following activities: Slip and Hold, Slip and Fall, Sleeping, Standing and Stretching, Wandering and Going up the stairs.

The algorithms and techniques from the research papers were then applied to the reduced version of the respective datasets. The accuracy rates, F-scores and weighted average were evaluated for each activity. The results from this study are then compared to the results achieved in Phase 1.

Testing Algorithms and Techniques on Other Datasets

Phase 3 of this study consists of reducing the activities from the PEM dataset to only those activities which are common between the PEM dataset and the previous dataset. This reduction process is done for each study just as in Phase 2. The techniques used in each study are applied to the respective reduced dataset.

The reduced PEM dataset is processed through the model of the respective study and the accuracy rates, F-scores and weighted average are evaluated for each activity. This is then compared to the results established from Phase 1 and Phase 2 of this research. For this exercise, the models from the techniques and algorithms which were established in

Phase 1 are applied to the original PEM dataset where for each technique and algorithm, the accuracy rating and F-score values are evaluated for each activity.

Results and Discussion

Key results of this project are:

1. Reproduction is possible but difficult
2. Reduction did not have an adverse effect on recognizing activity from spatial data
3. Using techniques from different datasets can be effective

Phase 1 – Reproduction of Dataset

The purpose of the first phase is to reproduce or replicate the techniques as described in their respective research papers. Through these techniques and algorithms, a predictive model is constructed to classify the activities in the HAR dataset. In this phase, the results are reproduced by applying the techniques/algorithms stated in each research paper to their respective dataset and the achieved results are compared to the results attained by each study. This was done by windowing the data in some datasets, and by generating a number of columns by taking the spatial data and applying various mathematical and sound processing formulas, which allows for more avenues to find the patterns while classifying the data (Figures 1 and 2).

Figure 1: Comparison of a dataset across all phases (Part 1)

Algorithm		k-Nearest Neighbor s (k=1)	k-Nearest Neighbor s (k=3)	Nearest Centroid Classifie r
Results	Metric	Weighted Average		
Replicated (P1)	P1 Accuracy	90.3%	91.2%	42.1%
	P1 F-Score	68.0%	70.9%	19.5%
Reduced (P2)	P2 Accuracy	44.1%	80.4%	42.0%
	P2 F-Score	43.1%	80.5%	40.0%
Matched (P3)	P3 Accuracy	100.0%	100.0%	100.0%
	P3 F-Score	100.0%	100.0%	100.0%

Figure 2: Comparison of a dataset across all phases (Part 2)

Algorithm		Linear Discriminant Analysis	Quadratic Discriminant Analysis
Results	Metric	Weighted Average	
Replicated (P1)	P1 Accuracy	60.4%	55.3%
	P1 F-Score	26.7%	26.6%
Reduced (P2)	P2 Accuracy	42.1%	39.3%
	P2 F-Score	40.2%	38.9%
Matched (P3)	P3 Accuracy	100.0%	100.0%
	P3 F-Score	100.0%	100.0%

Most of the datasets did not contain the code used by the original teams, thus necessitating the need to create new methods to reproduce the data for classification from the raw spatial data. A side effect of creating the methods from scratch is that in cases where the explanation is insufficient to recreate the conditions used by the original teams. One such example of this issue is with the second paper, which was not replicated successfully. For the other papers the experiments were replicated to within a small margin of error.

Phase 2 - Reduction of Dataset

In the second phase, the method of processing data from Phase 1 was modified to add a filter which removed extra data to match the sensor type, count, and activities in common with the PEM dataset. The algorithm or techniques is then re-applied to the reduced dataset. The results achieved from this phase are compared to the results achieved in Phase 1 to assess the degradation of quality. This meant that the difference between the two was the data that arrived at the algorithm, thus ensuring a clear indication of the effect the reduction has.

In the following datasets, two types of reductions were to be done, the removal of spatial data from additional sensors that had no counterpart in the PEM dataset. The second type of reduction was the removal of activities that were not in common with the PEM dataset. Other changes made to the labelled data was the combination of activities which was done in a single activity during the PEM dataset, as well as the removal of activities that contained a similar name to the one used with the PEM dataset but did not follow a similar spirit. For most of the datasets the reduction turned out to be of benefit to the ML algorithm, as for most of the cases, the reduction caused the results to become more stable, with the difference between the accuracy and f-score decreasing in most of the cases. The accuracy did not experience a large difference during the reduction. The exception was the paper that was mentioned in the first phase, which fell to 0%.

Phase 3 - Reduction and Formatting of PEM Dataset

In the third phase, the filters used in the second phase were modified to take the data from the PEM dataset, thus establishing a connection between the two datasets. Finally, all the algorithms and techniques are applied to the processed PEM dataset. The results achieved from this phase are compared to the results achieved in Phase 2 to assess how the techniques and algorithms perform on a different dataset. The PEM dataset contains a different number of natural activities than the other referenced datasets. Consequently, for most of the datasets, most of the activities were omitted except for the "Standing", "Walking", "Downstairs", and "Upstairs". Datasets that contained the "Falling" activity were kept as well.

Running the algorithms on the reduced PEM datasets yielded good results, with some algorithms reaching a perfect score during the classification. The exception was the MobiFall dataset, which was not implemented successfully across all phases. Considering the results from the three phases, it can be concluded that machine learning can be adapted with minimal changes and be applied to different sources and activities. The flexibility shown during this process implies that spatial data collected from different trackers and sensors would reliably predict the ongoing activities using these techniques.

Recommendations

Key recommendations of the effort are:

- Use in patient monitoring

One of the bigger strengths that was offered in this research is the demonstration that falling can be predicted. This allows for the development of a system which has the patients wearing a sensor that transmits the spatial data for the patient, and a machine would classify what the patient is doing. If the patient has fallen and is hurt enough to not be able to request help, the system would detect the fall and that the patient is still down, thus raising a warning for help to be dispatched.

- Refinement of fitness tracking

Fitness tracking apps already attempt to classify the actions of the users. The processes tested in this research can be used to further refine the activity tracking, allowing for a further breakdown in the analysis. This can be done by detecting when the user has stopped moving or has sat down to determine rest periods.

- Mapping aid Voluntary Geographic Information (VGI)

One aspect of the detection is when the user is going up or down an elevation. This can be used in VGI to note where there is a slope.

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EPILOGUE

Geospatial Information in a Digital Society: The Future of Geospatial Information

Charles Galdies

The highly varied contributions made by the authors in this book is a strong proof that geospatial data is slowly changing the way we live and interact with each other and our environment. Geospatial information has been a game changer in the way that we interact with our environment. This is because it helps us understand and interact with the current state of all geographic objects, depicting features such as physical relief, political boundaries, natural resources and environmental hazards, infrastructure and population dynamics. Geospatial data is also becoming extremely important to businesses because it allows them to use automation and predictive technologies to provide services such as traffic management or shipping by location.

Malta sees Information Communication and Technology (ICT) as a key enabler for its Digital Economy. It is here where geospatial data becomes such a critical component in an increasingly digital society. This book shows how it is used in many aspects of our lives, such as in transportation, agriculture, urban planning, heritage conservation, crime mapping, etc. Intricately linked with geospatial data is the provision of sub-hourly digital observations of the earth and its functional components (land, sea, air, etc.) which will in turn be driven by the collective need to have such geospatial information to people in a timely manner and in a cost-effective and sustainable way.

Geospatial Information in an increasingly Digital Society

Our society is becoming more and more digitalized. We are using our smartphones to order food, to book our holidays, to manage our finances and even to buy a house. The digital revolution has changed the way we live our lives. However, one of the most significant consequences that this digital revolution has had on our society is the way we interact with maps. Nowadays, we can use maps to find out what is happening in other countries, where our friends are located or where the nearest restaurant is located.

The content of this book shows the degree of Geospatial intelligence, or GEOINT in short, that is pervading modern society. It is without any doubt being led by the highly 'volatile' information technology that is still obeying Moore's Law. Recently, Geospatial intelligence is being augmented with the introduction of drones, and methods of creating maps have changed dramatically. In addition, new technologies are making it easier for organizations, including National armed forces, to share their data more quickly.

This book provides a close glimpse at the level of GEOINT that we can achieve at research level. All the work that is being presented makes use of a geographical information system (GIS) to capture, store, analyse, manage and display geospatial data to help us answer questions about the earth, and more importantly, to manage our local environment from a socio-economical, cultural and environmental point of view. In essence, GIS is a tool that allows users to see their world in a new way by revealing patterns and relationships among different geographic phenomena. Indeed, this book presents this in a comprehensive manner, with articles ranging from the use of GIS to manage our cultural, historical and environmental heritage, law enforcement, cyber security and ICT, to the improvement of social wellbeing, infrastructure and land use planning processes.

The race towards collective spatial intelligence and predictive analytics

By moving the concept of GEOINT a step further, we reach to the idea of collective geospatial intelligence, where everyone would be able to work together to solve problems and make use of the best decisions. Such an approach is being seen by many as a significant leap forward towards improving society by making it more efficient and effective in the way how it functions. This is particularly relevant for societies that need to maintain their level of competitiveness for intellectual resources and all related services. The idea of collective intelligence is an intriguing concept as it refers to the shared intelligence that emerges from many different people.

One important scope of collective GEOINT is what is known as geospatial predictive analytics (GPA). This is a branch of predictive analytics that focuses on making predictions about how an event will unfold in the future based on its past, present, and future locations. It can be used to predict events like crime rates or traffic accidents by analyzing the geographical location where they take place. It is slowly also becoming an effective tool for monitoring natural disasters, wars, epidemics and other events that may cause human displacement.

Perhaps the next type of spatial training to happen in Malta could be on ways how to address collective GEOINT to the benefit of Maltese society. It would be very interesting to see how local events can be influenced and constrained by spatially correlating occurrences of geospatial locations (our infrastructure, sociocultural issues, etc.) with

Malta's environmental factors. Can this approach give us the ability to predict where certain crimes will happen, or what resources will be needed to manage our cultural heritage, or even when and where it is optimal to deliver, in the most effective and economic manner, utility services such as the provision of potable water?

This explains why GPA lies at the very heart of the future of productivity and customer service. It will make it easier for businesses and service providers to provide a better product and customer experience. GEOINT will enable people and machines to work together more effectively by promoting a more productive, spatially seamless workforce. The amount of data that the global community is producing is indeed mind-boggling: according to Forbes (2022) there are 2.5 quintillion bytes of data created each day at the current technological pace - something which is only accelerating with the growth of the Internet of Things (IoT). The world has never been so rich in data before. It has been estimated that over the past two years 90% of all new data came to fruition because of IoT. The amount of data (and spatially tagged information forms a good chunk of this data) is expected to double every two years due to the rise in digital technology.

To handle this growth, both the public and private enterprises will be requiring IT infrastructure and a highly skilled workforce that is up to date with current and anticipated needs. In this regard, this book provides a glimpse of the current skill of some of Malta's current workforce coming from various sectors, that is suited to solve and improve the use and analysis of spatial data in order to answer modern-day spatial problems.

Geo-information science is one of the fastest-growing fields in the world. The field is expected to grow quickly over the next decade, with a projected growth rate of 10.5%. This is an excellent field for anyone who is interested in computer science, earth systems, geography, geology or statistics. The future of Geospatial Information is looking bright. We are just at the beginning of what can be done with geospatial data and it's exciting to see where this field will go in the next few years

COLOUR IMAGERY

This section depicts colour versions of selected images from the chapters

Chapter 1

Figure 1: Map of the Malta LUQA runways. Coordinates: N35°51.45' / E14°28.65'. Elevation is 297.0 feet MSL. Magnetic Variation is 3° East.

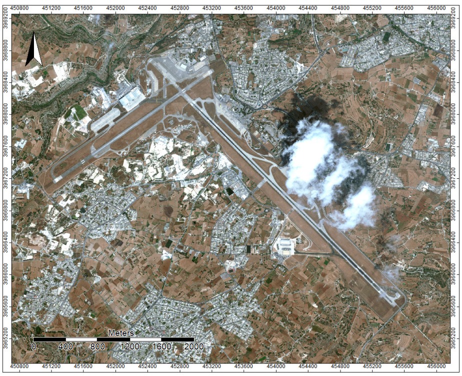
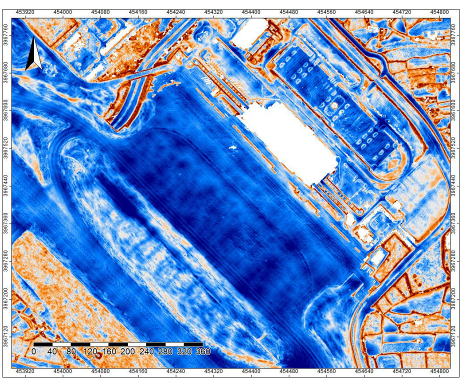
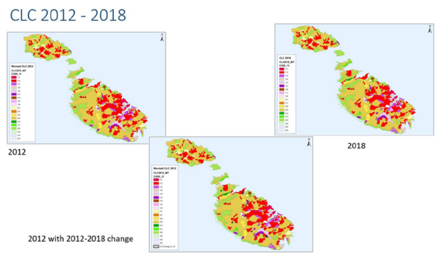


Figure 6: Spatial distribution of the wetness index over Apron 9, in front of terminal building, but towards air side at Malta Luqa Airport.



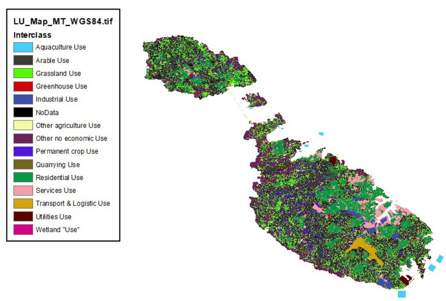
Chapter 2

Figure 2: CLC maps for Malta for 2012, 2018 and respective change layer map



Source: EEA, 2022a

Figure 4: Land Use Attribute (LUA) map derived by the PA as part of the development of the EEA's LULUCF instance.



Source: Planning Authority (2022)

Chapter 3

Figure 3: UAV based pointcloud

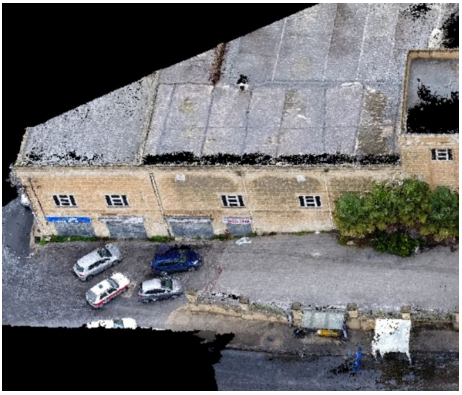
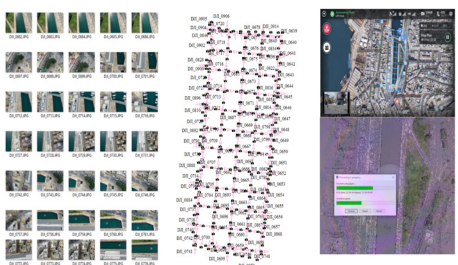


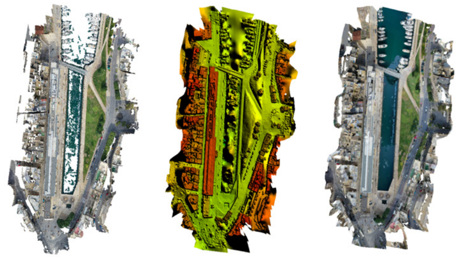
Figure 4: Handheld Laser scanner

Figure 6a: Dock 1 process: Drone Capture, GIS locations, Grid mapping and pointcloud generation



Drone Capture GIS locations Grid mapping and pointcloud generation

Figure 6b: Dock 1 outputs: Pointcloud, DSM, Mesh



Pointcloud DSM Mesh

Chapter 4

Figure 3: Isochrones (Generated from ACS), related sites, and geological formations for XMX 0001 - Xemxija 'Temple', San Pawl il-Baħar

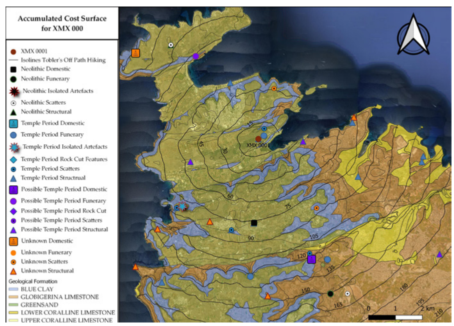
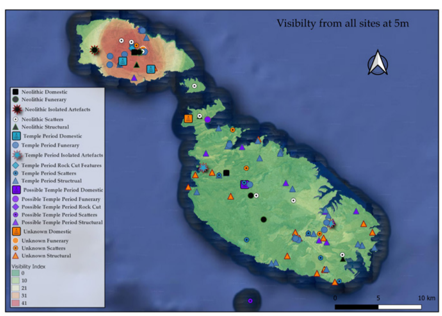
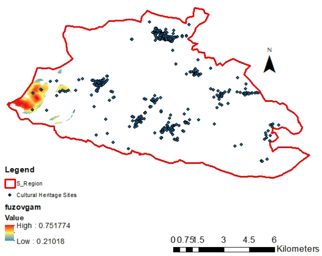


Figure 6: Cumulative Viewshed from all sites under study, 5m target



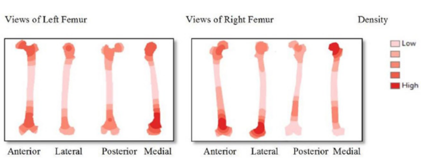
Chapter 5
Figure 3: Fuzzy Overlay Analysis results



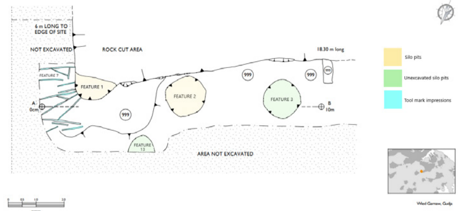
Chapter 6
Figure 5: Human remains inventoried and logged from the passageways at the Chapel of San Girgor, stacked on wooden shelving units and placed in Passageway 3

Source: Imagery captured in October 2020

Figure 8. Heat map showing 'hot spots' of tool/cut marks. Darker red zones indicate high density and lighter coloured zones represent lower densities

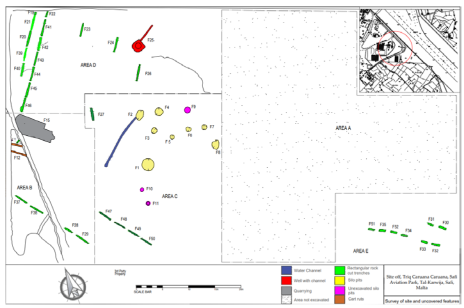


Chapter 7
Figure 4: Plan of Ta' Garnaw Gudja site



Source: SCH archives

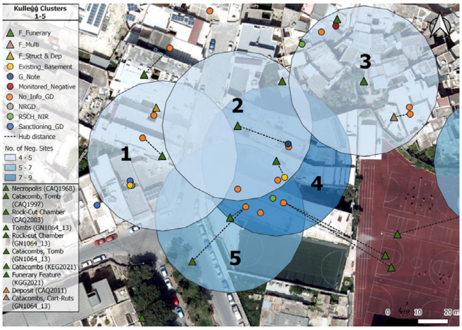
Figure 5: Plan of Tal-Karwija Ħal Safi site



Source: SCH archives

Chapter 8
Figure 3: Triq il-Kulleġġ Clusters

Figure 4: Triq il-Kulleġġ Clusters 1-5



Chapter 9

Figure 2: A GIS generated map showing the pill boxes in Malta during the Second World War

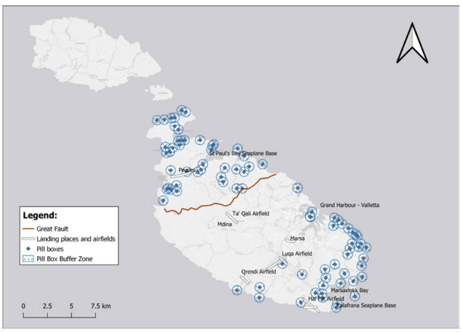
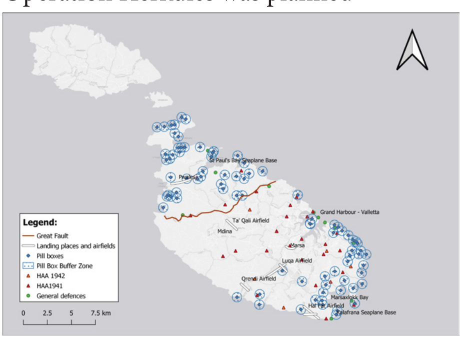


Figure 4: A GIS generated map showing all the defences in place in 1942, the time that Operation Herkules was planned



Chapter 10

Figure 4: Spatial autocorrelation analyses with the indicator 'Getis –Ord G*' and with the indicator 'Moran's I'

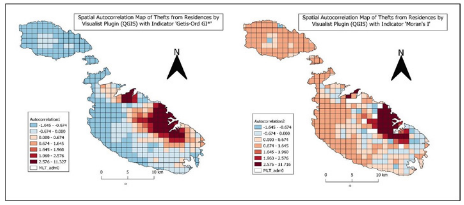
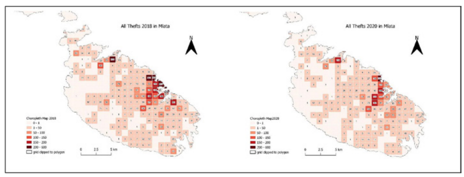


Figure 8: Theft cases counts and hotspots thematic maps for the years 2018 and 2020

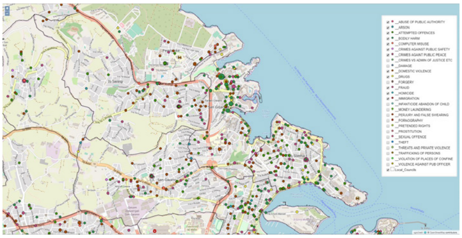


Chapter 11

Figure 2: Heatmap from participant exploring map features on SonoMap

Chapter 12

Figure 1: Graduated symbology according to the total crime for the selected category



Source: Formosa, 2018, https://www.crimemalta.com/QGIS/geopol2018_maincateg_cluster/geopol2018_maincateg.html

Chapter 13

Figure 3: Crime Severity Index for Malta Localities 2016. Crime is indicated by locality as weighted crime score per 1000 inhabitants

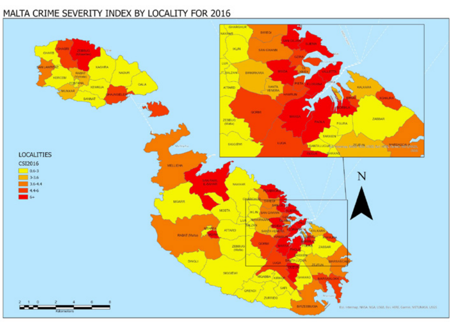
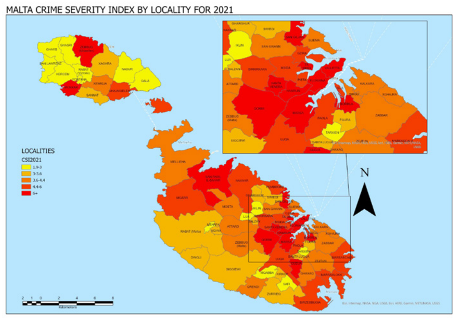
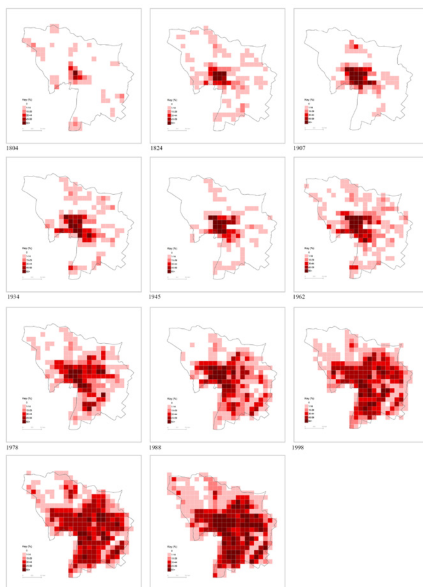


Figure 4: Crime Severity Index for Malta Localities 2021. Crime is indicated by locality as weighted crime score per 1000 inhabitants



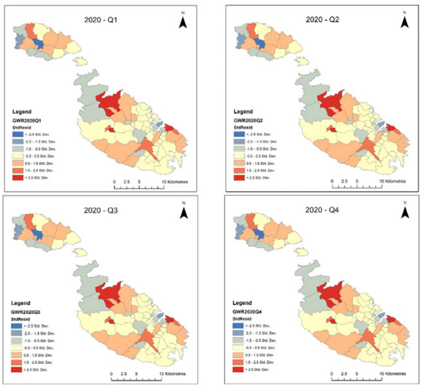
Chapter 14

Figure 5: 100m2 grid map showing percentage classification of build-up areas for all reference



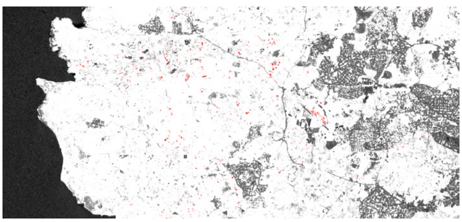
Chapter 15

Figure 5: The maps of the Standard residual from the GWR model for each quarter of year 2020



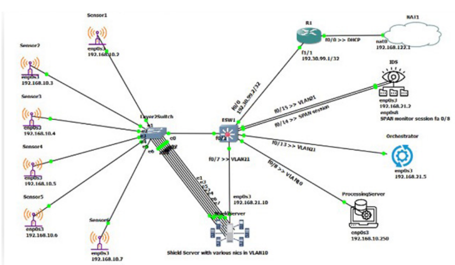
Chapter 16

Figure 5a. Grape Fields in the Northwest of the islands 2020 and Figure 5b Potatoes field in the South east of the Islands 2020



Chapter 17

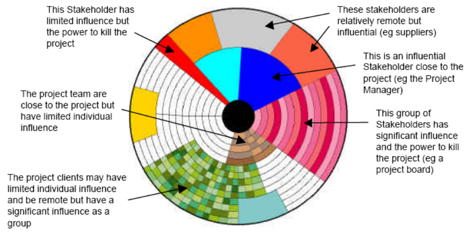
Figure 2: Simulation Setup for Solution



Chapter 18

Figure 1: Stakeholder Circle Methodology

Source: Bourne (2006)



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