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„Comparison of ArcGIS and QGIS for Applications in Sustainable Spatial Planning“

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List of Abbreviations

AHP	Analytical Hierarchy Process
API	Application Programming Interface
CNES	Centre National d'Etudes Spatiales
CRS	Coordinate Reference Systems
DBMS	Data Base Management System
DHM	Digital Height Model
EEA	European Environment Agency
EPSG	European Petroleum Survey Group Geodesy
ESRI	Environmental Systems Research Institute, Inc.
EU SDS	EU Sustainable Development Strategy
FLOSS	Free/Libre or Open Source Software
FSF	Free Software Foundation
GDAL	Geospatial Data Abstraction Library
GEOS	Geometry Engine Open Source (Library)
GQM	Goal-Question-Metric Method
GRASS	Geographic Resources Analysis Support System
GUI	Graphic User Interface
ISO	International Organization for Standardization
LfU	Bayerisches Landesamt für Umwelt
OGC	Open Geospatial Consortium
OGD	Open Government Data
OGR	OpenGIS Simple Features Reference Implementation
OSGeo	Open Source Geospatial Foundation
OS	Open Source
OSI	Open Source Initiative
OSS	Open Source Software
PCSS	Proprietary Closed Source Software
SAGA	System for Automated Geoscientific Analyses
SDK	Software Development Kit

Abstract

This paper looks into applications in sustainable spatial planning by comparing the software quality of the leading, proprietary *ArcGIS for Desktop 10.2.2* software with the open source *QGIS Desktop 2.6* software. The use of Geographical Information Systems (GIS) brings great advantages for the work of planers, however the specification and complexity of the program makes it expensive and the purchase has to be considered wisely, especially in small planning offices.

In order to compare the software quality of the programs the definition of the International Organization for Standardization's norm *ISO/IEC 9126* and the underlying indicators functionality, reliability, usability, efficiency, maintainability, and portability are used. As software quality contains objectively measurable factors as well as subjective criteria, method triangulation will be applied to cover all relevant aspects. In this sense a discourse analysis is implemented together with an expert interview, *CartoEvaluation* Method and Test Analysis. The test analyses are evaluated with Checklist-based testing based on a schema that was created with *Goal-Question-Metric (GQM)* Approach as well as *Analytical Hierarchy Process* (AHP).

As a result, this paper provides guiding principles for spatial planning offices concerning the possibility of replacing ArcGIS software through QGIS software depending on their specific tasks as well as skills of their employees. According to the principle "*Software is a tool, not a target*" the result will not be to highlight one of the GIS software but to conduct an evaluation of the two GIS software concerning their suitability for specific cartographic and analytic tasks.

Kurzfassung

Diese Arbeit betrachtet Anwendungen in der nachhaltigen Raumplanung indem die Softwarequalität der marktführenden, proprietären *ArcGIS for Desktop 10.2.2* Software mit der Open-Source-Software *QGIS Desktop 2.6* verglichen wird. Die Verwendung von Geographischen Informationssystemen (GIS) birgt große Vorteile für die Arbeit von Raumplaner. Jedoch bringt die hohe Spezialisierung und Komplexität des Programmes hohe Kosten mit sich und die Anschaffung einer Lizenz muss gerade in kleinen Büros, genau abgewogen werden.

Um die Qualität der Programme zu vergleichen wird die Definition der Internationalen Organisation für Standardisierung ISO/IEC 9126 sowie ihre bestimmenden Faktoren Funktionalität, Zuverlässigkeit, Benutzbarkeit, Effizienz, Änderbarkeit und Übertragbarkeit herangezogen. Da Softwarequalität sowohl objektiv messbare als auch subjektive Faktoren beinhaltet wird Methodentriangulierung verwendet um alle Aspekte abdecken zu können. In diesem Sinne werden eine Diskursanalyse, ein Experteninterview, *CartoEvaluation* Methode sowie GIS Testanalysen durchgeführt. Die Testanalysen werden mit Hilfe von Checklisten-basiertem Testen evaluiert wobei das Evaluationsschema mit *Goal-Question-Metric* (GQM) Methode sowie *Analytical Hierarchy Process* (AHP) erstellt wurde.

Das Ergebnis dieser Arbeit ist ein Anhaltspunkt für Raumplanungsbüros bezüglich der Möglichkeit eine ArcGIS Lizenz durch QGIS zu ersetzen unter Berücksichtigung der spezifischen Aufgaben einer Firma sowie den Fähigkeiten ihrer MitarbeiterInnen. Dem Leitmotiv der Arbeit „Software ist ein Werkzeug und kein Ziel" folgend, wird keines der Programme herausgestellt, sondern die spezifischen geographische und analytische Anwendungsmöglichkeiten untersuchen.

Preface

The aim of this thesis is not to elaborate upon which software is the better GIS software. This thesis is meant to build upon the understanding that software itself is a tool and not a target. The suitability of one of the GIS software will always be dependent on the user or company with their specific needs and resources.

Furthermore the author distances herself from ideological considerations concerning open source and proprietary software.

1 Introduction

Today, the field of spatial planning is facing the challenge of working to enhance sustainable development. The goal of sustainable development has been formulated by the United Nations in the AGENDA 21. Spatial planning is a very complex and interdisciplinary field including disciplines like architecture, engineering, geography, sociology, economy, or ecology. Consequently planners need a range of different software applications to fulfill the specific tasks of a spatial planning office. Geographical Information Systems (GIS) are an important and powerful tool in sustainable spatial planning and can facilitate and improve the planning process. The most popular GIS software used in Spatial Planning is which has been under development since the 70ies is the leading software on the GIS market. It is widely common for academia, government and commercial agencies. The proprietary software provides a wide range of mapping and spatial analysis tools but is also rather expensive to purchase. However, there are also open source (OS) software solutions available in the field of GIS systems. Since 2002 the OS GIS software QGIS has been under development and its quality and popularity is growing rapidly.

"Over the last couple of years open source software has done a ninja attack, the quality of the FOSS GIS software now is nothing more that remarkable" (DUGGAN 2013).

"Open source software is now under serious consideration in many organizations."

(KAVANAGH 2004: XVII)

Due to financial reasons, there is great potential and interest in using OS GIS in small and medium sized planning offices. However there is a lack of scientific studies on the use of OS GIS in spatial planning. Consequently it is necessary to systematically compare the possibilities of the open source program QGIS as an alternative to the established proprietary ArcGIS software in the field of sustainable spatial planning.

1.1 Aim of the Thesis and Research Question

Against this background, the aim of this thesis is to fill the information gap concerning the implementation of OS GIS software in the spatial planning discipline. Thus, in this thesis, GIS tasks conducted in sustainable spatial planning will be implemented and compared with the proprietary software ArcGIS for Desktop and the OS software QGIS. According to the principle "*Software is a tool, not a target*" the result will not be to highlight exclusively one of the GIS software. The aim is rather to analyze the suitability of the two GIS software for specific cartographic and analytic tasks in the field of spatial planning.

Currently there is no reviewed literature on the use of ArcGIS and QGIS software available, neither for general GIS tasks not for specific spatial planning analyses. Merely certain blog entries and discussions on internet forums discuss similarities and differences of ArcGIS and QGIS software. These are however neither systematic nor dedicated to spatial planning.

The only field which is also relevant for spatial planning, in which a systematic evaluation exists is cartography. There is a comprehensive comparison of cartographic features of different GIS software which include ArcGIS and QGIS. Nevertheless the study dates back to the year 2009 where QGIS was still in an early stage of development.

As a result, there is a need for a systematic, contemporary approach which includes cartographic aspects as well as spatial analysis with a focus on spatial planning tasks. In this manner, this thesis will be a basis to support the decision making process for spatial planning offices concerning their software choices.

Research Questions

"What are the similarities and differences in applications for sustainable spatial planning with ArcGIS and QGIS?"

1. What are the *parameters,* namely development and distribution, cost and licenses, training and support of ArcGIS and QGIS?
2. How does the *software structure* and *functionality* of ArcGIS and QGIS compare?
3. How do *ISO's software quality attributes* compare for equivalent *spatial analysis* of the same geodata with ArcGIS and QGIS software?

1.2 Structure and Research Design

In the theoretical part the basics of GIS applications and their use in the field of sustainable spatial planning will be demonstrated. Furthermore an overview of the discussion between proprietary and open source software will be given. Beyond, software quality attributes, defects and principles for Graphic User Interface (GUI) design will be presented, as well as will evaluation methods.

The practical segment contains a systematic comparison of the two GIS programs. In the beginning the parameters of ArcGIS and QGIS will be analyzed. These include the software's development and distribution, cost and licenses, as well as opportunities for training and support. Subsequently the software structures and functionality will be compared. This encompasses installation process and GUI, Data Formats and Data Management, Raster and Vector Analysis Tools, Scripting and Automation, as well as Visualization and Mapping. The comparison of parameters, structure and functionality will be methodologically based on literature research and CartoEvaluation Method.

Moreover several test analyses will be implemented with ArcGIS and QGIS software in order to compare the quality of the software for applications in sustainable spatial planning. For the spatial analysis Open Government Data on European, Regional and City Level will be used. For the investigation of quality attributes the definition of the International Organization for Standardization's norm *ISO/IEC 9126* will be applied. For the evaluation schema of GIS software attributes Goal-Question-Metric Method (GQM), and Analytical Hierarchy Process (AHP), will be used.

Finally, the results of the different analysis will be discussed and compared in a systematic manner. The discussion will contain the results of literature research, discourse analysis of web forums and blogs, the expert interview, CartoEvalutation Method as well as the test analyses. The discussion will result in a collection of differences and similarities that will give planning offices a base to decide which software will be better suitable for their work and the qualification of their employees.

2 Use of GIS Applications in Sustainable Spatial Planning

In this chapter an overview of sustainable development and the use of GIS in this field will be given.

2.1 Sustainable Development

The verb “sustain” has Latin roots and means “to uphold” or “to keep” (DICTIONARY 2014). Thus “sustainable” describes something which can be maintained into the future. The idea of sustainability dates back till the 19th century. It arose in Central Europe, modern day German territory, when the capacities of forests were starting to be exploited. As a consequence structured forestry was implemented by local sovereigns and it was registered in forestry regulations that only a set amount of wood was allowed to be cut over a period of time that would then grow back. The modern concept of sustainable development cannot be traced to a single author. It arose in the 1970ies as an answer to the raising awareness on global environmental issues for instance due to the oil crisis (WHEELER 1998). Another important turning point was the 1972 publication “*Limits to Growth”* by MEADOW on the future of the planet which was ordered by the Club of Rome. The research revealed computer models for future development scenarios based on different figures of resource availability, agricultural productivity, birth control, or environmental protection. Most scenarios predicted a collapse of the global system with a turning point around 2030 (CLUB OF ROME 2014). In the same year the first *United Nations Conference on Environment and Development* was held in Stockholm. In 1987 the term “sustainable development” was defined by the United Nations at the *United Nations World Commission on Environment and Development* in a paper called *Our Common Future*, also known under the name *Brundtland Report* as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED 1987). However, this definition turned out to be limited to an ecological aspect and leaves a wide range of interpretation to the term “needs”.

Thus, the so called “three-pillar model” (ISIS 2014) or “planners triangle” (CAMPBELL 2001) claims, that sustainable development includes the three aspects ecologic, social, and economic development. The three aspects are interconnected. The concept represents the major model for sustainability in politics, economics, and research which was for instance used in the *Johannesburg Declaration*, the resulting paper of the *World Summit on Sustainable Development* in Johannesburg 2002.

The ecological aspect of sustainability describes the preservation of the world’s natural resources. The world ecosystem has limited capacities concerning the amount of resources that can be extracted and the amount of waste that can be absorbed. As a result the aim of ecological sustainability is the conservation of resources through economizing, efficient use, recycling and reuse on the one hand, and the reduction of pollution and waste on the other. Social Sustainability emphasizes intergenerational and inner generational justice and thus the equal access and distribution of the available resources. It is concerned with protection of human health, protection of diversity, people’s participation in decision making and access to necessities as well as knowledge. A sustainable economy is an “an economy that values the long-term health of human and natural systems” (WHEELER 1998: 442). This economy supports the restoration of past environmental and social damage and prevents future ones. Furthermore it is human-centered which means that it meets human needs and provides satisfying and meaningful work at decent pay for its employees. Another important aspect is the focus on the local level. A sustainable economy strives for local ownership, local control, local investment, and supports the use of local resources and production for local markets (Ebenda 1998).

Sustainable development represents a comprehensive long-term goal of the EU. The strategy was first introduced formally to EU policies in 1997 in the *Treaty of Amsterdam*. In 2001 at the *Gotheburg Summit* the first EU Sustainable Development Strategy (EU SDS) was implemented and has since been continuously adopted according to new challenges and knowledge. The strategy includes contents from the 2002 World Summit on Sustainable Development in Johannesburg and the Millennium Development Goals agreed on in 2000. The EU SDS combines the goals of economic growth, social cohesion and environmental protection and consists of seven key topics:

1. Climate Change and Clean Energy
2. Sustainable Transport
3. Sustainable Consumption & Production
4. Conservation and Management of Natural Resources
5. Public Health
6. Social Inclusion, Demography and Migration
7. Global Poverty and Sustainable Development Challenges

The implementation of these needs is to be practiced within all aspects of a society including politics, industries and private households, public and private associations, as well as planning offices (EUROPEAN COMISSION 2014). In the next chapter the topics relevant for spatial planning will be presented.

2.2 Tasks of Sustainable Spatial Planning

The European Conference of Ministers responsible for Regional Planning (CEMAT) defined spatial planning in the European Regional/Spatial Planning Charter which was adopted in 1983 in the following way:

"Regional/spatial planning gives geographical expression to the economic, social, cultural, and ecological policies of society. It is at the same time a scientific discipline, an administrative technique, and a policy developed as an interdisciplinary and comprehensive approach directed towards a balanced regional development and the physical organisation of space according to an overall strategy" (COUNCIL OF EUROPE 1983).

This overall strategy can today be summarized under the keynote of sustainable development. According to the planner's triangle spatial planning would ideally grow the economy, distribute this growth equally, and avoid environmental degradation while doing so. However these issues cannot be addressed to the same degree at the same time. As a result, planners work within a tension that exists among these three goals and try to achieve a balance between them (CAMPBELL 2001).

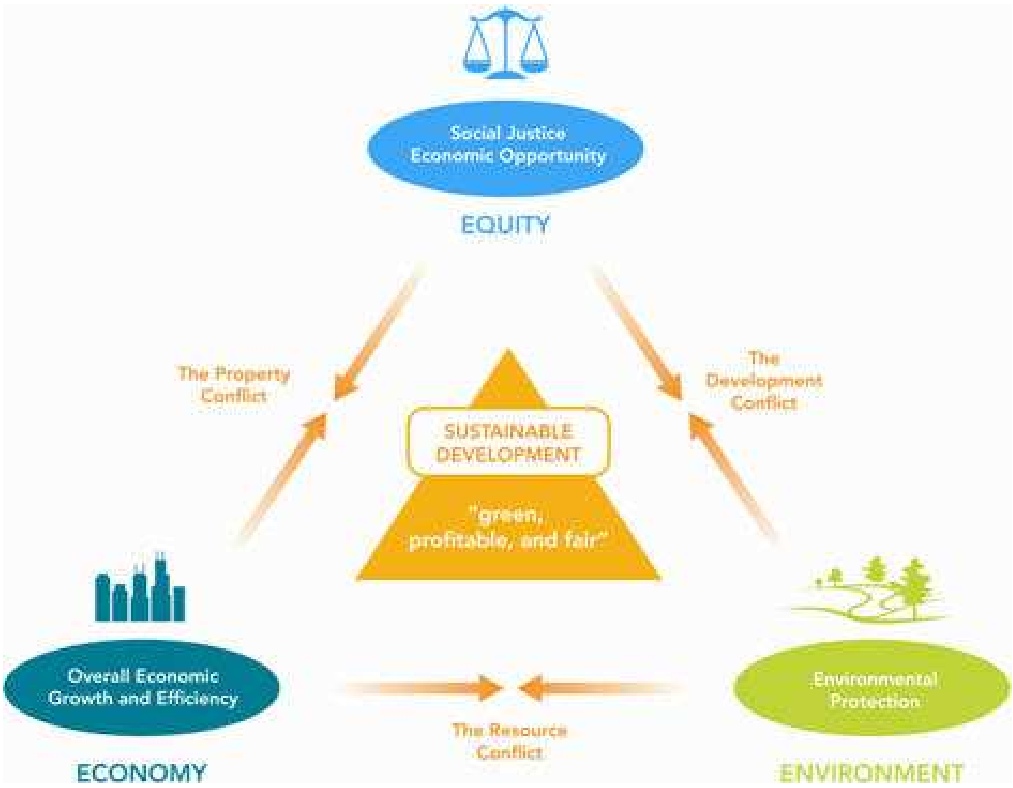


Figure 1 Planners Triangle, Source: ABUKHATER 2011

Viewed from a spatial perspective, cities play a major role in sustainable development. 80% of EU's residents live in cities (EU 2005) and cities are centers of consumption of energy and other resources. The Habitat II Conference in Istanbul "City Summit" emphasized, that cities are places where global problems are concentrated (UN-HABITAT 2003). However cities have always been the starting points for societal changes and centers of innovation. Thus they are keys to sustainable spatial development and urban sustainability became important with the implementation of the Agenda 21 (Cf. HANSEN & SCHRADER 2001). "Cities are therefore major centres of energy use, waste production, and the generation of heat-trapping greenhouse gases (GHG); and due to their influence over energy supply, management, traffic control, waste management, and urban planning, they are also logical focal points for efforts to reduce GHG emissions…" (MOSER 2006: 1). Concepts for sustainable urban development emerged in different cities through top-down as well as bottom-up initiatives. During the 1996 UN Habitat II City Summit in Istanbul outlines for a global urban sustainability strategy were shaped (WHEELER 1998). Scientific research and flagship projects show that "Green Urbanism is not an oxymoron" (BEATLEY 2003).

The progress in sustainable development depends on sustainability issues "diffusing into all existing planning and development processes" (WHEELER 1998: 443). However several priority themes appear repeatedly in literature and political agendas with respect to spatial planning tasks. Key fields of urban and regional planning are amongst other energy saving measures and the implementation of renewable energies, the preservation of natural areas through the creation of compact cities and avoidance of urban sprawl, the reduction of car traffic and the fostering of public transport networks, as well as pedestrian and biking friendly cities. Further topics are social cohesion and participation, preservation of natural areas, and the creation of green spaces in cities (MEHRHOF 2005, COLOMB ET AL 2012: 54

& WHEELER 1998). These fields cannot be viewed independently from each other, but are rather interconnected. For instance transport is highly dependent on the built structure and their distances. The following four fields will be investigated further

- Renewable Energies
- Compact Cities
- Transport
- Green Spaces

RENEWABLE ENERGIES (RE)

In the field of clean energy the EU adopted the “Climate and Energy Package” with the aim of fostering the growth of renewable energies to a share of 20% until the year 2020. In addition, the emissions needed to be reduced by 20% compared to the level of 1990 by 2020 (EUROPEAN COMMISSION 2014).
In 2012 the share of renewable energies in the EU 28 was 14% of the gross final energy consumption (EUROSERV’ER 2013). Between 2011 and 2012 the amount rose from 13% to 14.1% which is equivalent to a growth rate of 15.5% (EUROSTAT 2014a). The national shares vary heavily between the countries as can be viewed in the following chart which also contains values for non EU countries.
The Nordic countries have the highest share of renewable energies in Europe up to 60 percent and more. The UK, Netherlands, Malta and Luxembourg hold the lowest shares with less than 5%. Norway holds the highest share with 64.5%, Malta the lowest with only 1.4%. The majority of the European countries have a share of renewable energies somewhere between 10 and 20% (MURRAYBUCKLEY 1014).

Each EU country developed its own National Renewable Energy Action Plan (NREAP) as regulatory frameworks which represent detailed roadmaps of how the EU countries were planning to fulfil their 2020 goals (CASEY 2012). The national goals of EU 28 countries for 2020 vary between total shares between 10% and 47%. The individual value depends on the country’s initial renewable energy share, their technical potential, and economic capabilities. Bulgaria, Estonia and Sweden have already achieved their targets for 2020 in 2012 (EUROSTAT 2014a). According to the European Regional Development Fund transition regions and more developed regions will be required to focus at least 20% of their allocation on energy efficiency and renewable energy, while in less developed regions at least 6% needs to be used on energy efficiency and RE (EUROPEAN COMMISSION 2011).
Renewable Energies (RE) include wind power, photovoltaic, solar thermal, small hydropower, geothermal energy, heat pumps, biogas, biofuels, renewable urban waste, solid biomass, concentrated solar power, and ocean energy. However not all of them have the same importance for the future of Europe’s energy production. In the generation of renewable electricity, hydraulic power has the highest share with 43.9% followed by wind power (26.6%) and biomass (19.5%) (EUROSERV’ER 2013).

A study from the European Energy Agency revealed that wind energy can be a major part of securing Europe’s RE plans. The study of onshore and offshore wind energy potential took into account the technical potential but also the environmental and social constraints: “As a proven source of clean, affordable energy, wind resources clearly have a vital role to play in realising these goals” (EEA 2009). The wind power sector has grown exponentially in recent years and the European Wind Energy Association (EWEA) projects a rapid expansion. Thus it estimates an amount of 180 GW to be installed in 2020 which would cover 14.3% of Europe 27's total power supply. Greenpeace and the Global Wind Energy Council even suspect up to 385 GW wind power by 2020 (Greenpeace and GWEC 2006 cited in EEA 2009).

It's a task for spatial planners to determine where wind can be developed most effectively under consideration of environmental and social constraints as well as competition to other uses. Concerning cost-benefit analysis it is necessary to calculate the maximum amount of wind energy that could be generated with the help of wind speed data. Critical issues about wind mills are their noise and the visual impact on the landscape and thus may require a certain distance from settlements. If possible they shouldn't be in the view axis of certain places like heritage protected sights. From an ecological point of view, the danger for birds and bats of flying into rotor blades has to be considered. Wind parks should not be placed in protected natural areas. In the winter ice chunks freezing on the rotor blades and falling off can represent a danger for humans. Consequently wind mills should be placed off-road (CARMEN 2014).

For the installation of solar panels, the amount of solar radiation that reaches the area is obviously one of the determining factors in the planning process. In order to determine the solar radiation of a certain area, multiple variables need to be considered. First, the angle and duration of the radiation, and consequently the geographical position have a major influence on the radiation. The direct radiation is weakened by reflection and dispersion caused by ozone, oxygen, carbon dioxide, nitrogen, steam, and aerosol. As a result, the global or total radiation that reaches the earth is composed of direct radiation as well as diffuse radiation. Finally the topology influences the amount of radiation which reaches a certain spot. Relevant parameters are ground level, aspect, and slope which causes further shadowing effects. Not all of the incoming radiation can be used for the generation of energy with solar panels but a certain amount will be reflected again (BENDIX 2004: 47-61 & MALBERG 2007: 44f). The amount of solar radiation varies within the year, with peaks between May and August; the yearly average radiation is reached in March.

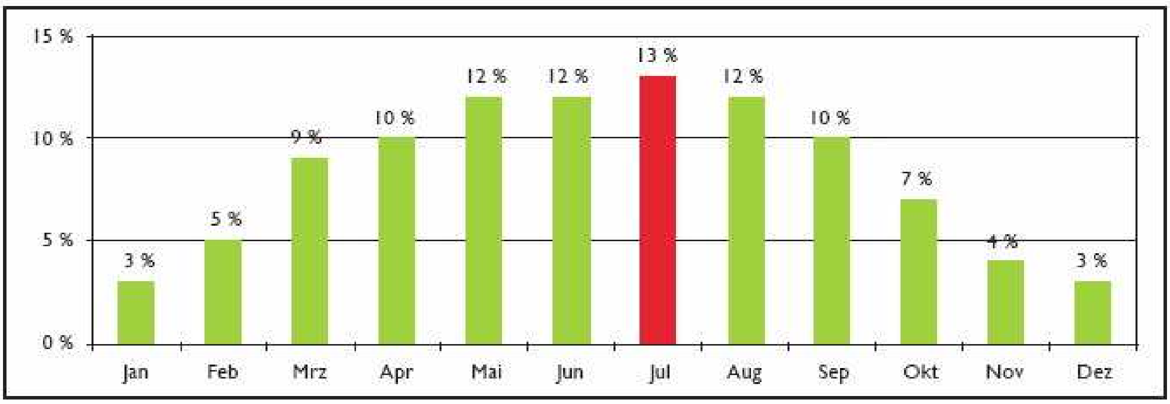


Figure 2 Solar Radiation during the year, Source: DR. NIEBUHR MEDIA UG 2014

COMPACT CITIES

"Urban form and land use patterns are primary determinants of urban sustainability" (BEATLEY 2003). Generally speaking it can be stated that compact city structures are more sustainable than dispersed ones. First, the construction of compact cities in contrast to dispersed cities leads to the reduction of land consumption, surface sealing and accordingly to preservation of rural environments. Within the EU's territory 4% of the land is covered by artificial surfaces. Within the period of 1990 and 2000 artificial land cover increased at a rate of 2.3 % per year. Between 2000 and 2006 the rate dropped to 1.5 % per year (EEA 2014b). Depending on the degree, surface sealing reduces or fully stops the provision of certain ecological services like infiltration and cleansing of water or micro climate regulation in urban areas (EEA 2014a).

Another point in favor of the compact city model is the fact that less resources and energy are needed. Due to the higher density, less construction and maintenance for housing, streets and supply infrastructure are necessary. This does not only apply to the initial provision of infrastructure, but also to the running consumption of resources like water, electricity or heating. With 40-60 persons per hectare European cities are generally denser than North American cities which have densities around 20 persons per hectare. As a result, they only produce half the per capita emissions (BEATLEY 2003).

Another positive effect of dense structures is the circumstance that inhabitants will have greater access to facilities. This includes commercial and leisure time, education, and health facilities. These facilities also have a higher occupancy rate than rural ones and hence are more efficient. Beyond, the compactness of city life influences the behavioral patterns of its residents. Shorter distances do not necessarily require car use which will reduce air and noise pollution and the consumption of resources that are needed to construct and recycle cars and to provide infrastructure like streets and parking lots for them (BEATLEY 2003). Closer proximity also holds greater potential for pedestrian and cycling friendly infrastructure an efficient public transport network which again encourages frequent use. These measures can lead to less car traffic and pollution and a higher mobility for social groups without a car like children, elderly people, or persons with a low income. The benefits of compact urban structures are not exclusively limited to ecological benefits but also provide social advantages. Dense cities lead to more interactions between inhabitants of different ages, genders, ethnicities and social status. An equal access to facilities further leads to equal opportunities and less segregation between social groups. Furthermore dense areas can be safer as populated public spaces provide more social control than abandoned suburbs. These factors can encourage overall greater social cohesion and equality and help avoid segregation. This is underpinned by the equal access to culture, commerce, and entertainment as well as more public spaces which enable more social encounters. However, a precondition for these developments is the existence of mixed neighborhoods in terms of residential and commercial areas as well as different population groups (ALEXANDER & TOMALTY 2002, MOLINI & SALGADO 2010 & BURTON 2000).

Compared to these advantages there are also critical arguments towards the compact city model. Opponents criticize that a densely built urban environment leads to a lack of urban green space, an overcrowded environment, and more congestion. Moreover the level of air and noise pollution is higher. Further, it is argued that the dispersed city model offers a higher quality of life by providing better landscapes, more light, ventilation, larger living spaces, more green, quietness, and a safe surrounding for children. Last but not least, the compact city is said to work against the concept of human-scale and undermines the psychological human need to be close to nature (ALEXANDER & TOMALTY 2002 & BURTON 2000). Consequently the challenge of a sustainable urban form lies in creating a "relatively high-density, mixed-use city, based on an efficient public transport system and dimensions that encourage walking and cycling" (BURTON 2000) and that allows for a high quality of life within the city boundaries by providing adequate green spaces. Cities like

Amsterdam show, that a high density doesn't necessarily require the construction of high-rise buildings but can be achieved with low rise building by promoting urban redevelopment and industrial reuse (BEATLEY 2003).

One way to regulate urban sprawl is through legislative restrictions from building outside of the city or taxes on second homes. Concerning this approach it has to be kept in mind that the compact city goes against the preference of the majority of people why prohibitions should be avoided. On the contrary, residents should be encouraged to live in the cities though their design: "If compact community policies cannot deliver greater affordability and a higher quality of life, then they are not likely to be successful in the long run" (ALEXANDER & TOMALTY 2002: 403). In order to stop the urban sprawl it is necessary to create dense cities that enable a higher quality of life. This concerns the creation of cheap and efficient public transportation, affordable quality housing, attractive sidewalks and bicycles lanes, well designed and maintained public spaces, as well as vibrant and lively streets with commercial and cultural opportunities. Especially important is the availability of a sufficient amount of green spaces in the city in the form of parks, natural areas, roof gardens, community gardens, or allotment gardens.

Viewed from a historical perspective, urban sprawl is the result of the routine use of fossil-fuel based technologies (GIRADET 2004). Thus it is only appropriate to go back to a more compact city model under the sustainable development model which aims at saving resources and getting independent of fossil fuels.

TRANSPORT

"Sustainable transport is a key challenge of the EU Sustainable Development Strategy (EU SDS). The strategy's objective is to ensure that our transport systems meet society's economic, social and environmental needs whilst minimising their undesirable impacts on the economy, society[,] and the environment" (EUROPEAN COMMISSION 2014).

In the EU 28 in 2012 the share of passenger cars was 83.3%, trains 7.4%, and busses 9.2% measured in percent in total inland passenger kilometers with no significant improvements towards less car traffic (EUROPEAN COMMISSION 2014). While the traffic outside of cities is even more likely to rise, spatial planning can set measures to work towards more sustainable traffic within cities. "Current transportation systems contribute to a complex web of urban problems such as air pollution, congestion, blight, suburban sprawl, ecosystem destruction, and social fragmentation" (WHEELER 1998).

There are several principles for the development towards more sustainable transport. One aspect concerns access to facilities by proximity. "Movement in cities is not an end in itself. We move in order to gain ACCESS to people and things" (SUSTRAN 1996). In car-oriented cities facilities are often spread out over great distances. Planners can reduce the need of residents to overcome distances by implementing a different land use. The creation of mixed-use areas and neighborhood centers enables residents to reach services everyday without having to commute (WHEELER 1998). Another important aspect for sustainable transport is the transportation hierarchy. In the 50s European Cities started to built for cars with wide streets, far distances, large spaces for parking lots and traffic organization that gave priority to cars for instance through traffic light circuits timed to the speed of cars. This car-orientation needs to be banished by changing the transportation hierarchy. The focus needs to be set on pedestrians, bikers, and public transport. An important element of reducing car traffic in the city is the maintenance of a fast, comfortable and reliable public transport system. This includes the provision for a single ticket for different kinds of transport at reasonable prices. To make sure that public transport runs faster than individual car traffic, trams and buses should have their own, dedicated lanes. Moreover, high frequencies of public transport modes make it more attractive. Different urban areas should be reachable within a short distance (BEATLEY 2003). Apart from fostering public transportation, "[t]he healthiest and most sustainable modes of transport are walking and cycling" (SUSTRAN 1996). Ways to make cities more attractive for pedestrians are the creation of pedestrian zones, play streets and traffic-calmed streets, wide tree lined streets that separate sidewalks from roads, and the creation of an attractive lively environment. For bikers the provision of separated bike lanes is favorable. Additionally bikers need sufficient bicycle parking facilities, especially at train stations and public buildings, ideally with rain protection (BEATLEY 2003). Service facilities like for instance automatic air pumps alongside streets as they are common in Copenhagen make biking more attractive for urban dwellers. Furthermore the integration between public transport and bikes, like for instance free biking transport on undergrounds as it is the case in Vienna facilitates biking.

At the same time, measures that make it harder to navigate with cars can be introduced like winding streets, speed bumps, pedestrian islands, or parking fees. The installation of free park and ride facilities outside of the city centers encourages commuters from the hinterlands to leave their cars outside of the cities. Pilot projects like car free Sundays, car-free housing estates, car-sharing, the revitalizing of parking lots, or free public transport use can make further changes in people's mindsets.

GREEN SPACES

In the 1950ies the trend of suburbanization started, as people prefer to live in a calm, green environment. Despite the beginning of a revitalization of inner city centers, many residents still aim for their own single family house to escape the city. Consequently creating livable cities that enable the experience of nature in the urban environment are important to counter urban sprawl. Thus the restoration of natural systems including green belts and water systems play a crucial role in sustainable urban planning.

The wish of residents to live in a green environment can be explained by scientific arguments. Nature has several positive physical effects on human beings. Green spaces as "lungs for the city" (CONWAY 2000: 10) are beneficial for air quality. On the one hand, they extract pollutants like fine particles; on the other hand they reduce the level of carbon oxide and raise the oxygen level by conducting photosynthesis. A tree-lined street has 85-90 per cent less dust than a treeless street. Cities that lack vegetation can have lower oxygen levels around 10–12 percent, while the average oxygen level is 20–21 per cent. Oxygen is crucial for human's mental performance and cellular health. Apart from particles, trees also filter noises and thus provide a space to escape the constant exposure to noise in cities. The provision of natural areas in an urban environment can further encourage humans to spend time outdoors. On average city dwellers spend at least 90 percent of their lives indoors. Being exposed to sunlight is essential for the human's production of Vitamin D. A deficiency of which causes weakness of the immune system and is related to seasonal affective depression in winter. An aspect that becomes important on hot summer days is the effect of green spaces on the microclimate. Generally, sealed concrete urban areas can be 5–9°C warmer than the surroundings countryside. While concrete reflects the solar radiation and consequently heats up its surrounding, an unsealed surface absorbs more radiation and additionally evaporates water which has a cooling effect. For instance a mature tree will daily produce an amount of up to 450 litres of water. Additionally, treetops prevent the solar radiation from reaching the ground (NICOLSON -LORD 2003).

Apart from the physical benefits, green areas also provide psychological and social services, that are part of social sustainability. As a positive effect on psychological and mental health, the reduction of stress and aggression can be mentioned. Studies have shown that viewing green spaces lowers the blood pressure and heart activity and relieves muscle tension (NICOLSON -LORD 2003). Additionally, experiencing nature in an urban environment evokes positive feelings like freedom or happiness (CHIESURA 2003). Moreover, public green spaces promote the development of social ties among city dwellers. Through the encouragement of park use, social integration, and interaction among neighbours are increased. Public green areas are places of encounter. No groups are excluded as the entry is free and these areas provide space for different groups of people, age, class, gender, or ethnicity. Consequently, "Sustaining diversity in parks can be an important part of sustaining diversity in the city overall" (LOW ET AL. 2005: 198).

To sum it up, urban green spaces fulfill an important ecological function for the urban environment and also immaterial and non-consumptive human needs, and are thus an essential part of sustainable planning.

The creation and maintenance of parks has to be viewed within its economic aspects. Urban space is a scarce commodity and consequently, green spaces are in competition with other possible uses like housing, commerce, or traffic infrastructure. Under the neoliberal planning paradigm, planning decisions are often made by cost-benefit analyses. As a result, green areas are considered less important than economically more profitable facilities like housing or shopping centers. Nevertheless parks have a huge economic impact on the real estate market as they raise the value of the surroundings. Thus new parks are created on old industrial sites that are being converted to mixed land-uses "as an attraction to enhance the use and value of land as a key commodity in capitalist society" (CLARK 2006: 6). Furthermore, urban green spaces are used as an element to raise the city's attractiveness and to promote a higher quality of life in the city in order to attract wealthy residents and tourists (CHIESURA 2003: 130).

EU regulations for newly developed regions propose 5.0-5.9 m^2 of green space per resident. Additionally everyone should have access to natural green within 280m.

2.3 GIS and Sustainable Spatial Planning

A geographic information system (GIS) is an "integrated collection of computer software and data used to view and manage information about geographic places, analyze spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organizing spatial data and related information so that it can be displayed and analyzed" (ESRI 2014). Other authors emphasize that GIS includes several components, namely hardware, software, data, users and applications, as well as the network for communicating and sharing digital information (LONGLEY ET AL 2005: 18-24 & LANGE 2013: 340).

The origin of modern GIS software dates back to the 1960s. The first computerized GIS was the Canada Geographic Information System (CGIS) which was created at the Department of Forestry and Rural Development by the English geographer TOMLINSON in 1962. It was used to prepare and analyze data from a wide survey of rural Canada (LANGE 2013: 339).

GIS software was further developed in the 1970s in order to automate cartography and map production. It took until the 1980s though for GIS software to be implemented in an efficient manner because sufficiently powerful computers became available at a reasonable price (LONGLEY ET AL 2005: 18). The market for GIS software grew at the end of the 1980s, fostered by companies aiming to increase their efficiency. Further development of GIS included automated map making and facility management. Other important developments for the evolution of GIS software were surveying and data capture technology, as well as GPS which enabled one to obtain positions and elevations on the earth's surface. Moreover the availability of satellite imagery in several wavebands at high resolution had an impact on GIS applications. Finally the evolution of the World Wide Web enabled the use of GIS software for clients via a web server (RAPER 2010: 77-83).

Today, GIS software is used in many different disciplines. "The field of geographic information systems (GIS) is concerned with the description, explanation, and prediction of patterns and processes at geographic scales. (…) GIS is a proven technology and the basic operations of GIS today provide secure and established foundations for measurement, mapping, and analysis of the real world" (LONGLEY ET AL 2005: XI). Fields of application include for instance environmental management, agriculture and forestry, transportation and infrastructure, demographics, surveying and risk management, energy calculations, and many other industries (TU MÜNCHEN 2014 & SCOTT & JANIKAS 2010: 27). The field that will be primarily focused on in this thesis is sustainable spatial planning. In spatial planning spatial components and thus GIS obviously play an essential role. Spatial planning is a complex topic which includes several fields like architecture, engineering, geography, sociology, economy, politics, and ecology. Thus decision making in spatial planning involves different actors and aspects of society. GIS can enable "making social decision-making processes better, stronger and more accessible" (WORRALL 1990). Another advantage of GIS is that it can process a large amount of data (BERNHARDSEN 1992). In this way, decisions for a long term sustainable development can be facilitated with the help of GIS. Additionally, GIS "allows for more precise mapping of environmental problems" (MEHRHOFF, W.A. 2008: 443). The use of maps further facilitates the tasks of spatial planning (COLOMB ET AL 2012: 69). In this context the European Union launched the European Observation Network for Territorial Development and Cohesion (ESPON) in 2007. The goal of the project is to *"[s]*upport policy development in relation to the aim of territorial cohesion and a harmonious development of the European territory by (1) providing comparable information, evidence, analyses and scenarios on territorial dynamics and (2) revealing territorial capital and potentials for development of regions and larger territories contributing to European competitiveness, territorial cooperation and a sustainable and balanced development" (EU 2014). This underlines the importance of visualizing data in the spatial planning process. The possibilities in GIS are not limited to visualizing data though, but the main purpose of the software is spatial analysis. These can focus on a description of the state of the art but also on changes over time, thus showing past developments or future scenarios (GARNER 1990).

3 Proprietary and Open Source Software

As this thesis includes working with a proprietary and an OS GIS software, this chapter will be dedicated to the emergence and development of the two types of software as well as their characteristics and specific advantages.

3.1 The History of Software Development

The term software describes "computer programs, procedures, and possibly associated documentation and data pertaining to the operation of a computer system [IEEE 610]" (GTB 2013). In general software can be divided into two groups. The first one is proprietary software, also referred to as commercial software, nonopen, nonfree, closed software, or proprietary closed source software (PCSS). The second category describes open source software (OSS), also known as free software or "Free/Libre or Open Source Software" (FLOSS) (KAVANAGH 2004: 1-2). The main difference between the two categories lies in the openness of the software's source codes and the licenses for their usage: "Open source software is software that can be freely used, changed, and shared (in modified or unmodified form) by anyone" (OSI 2014).

Before the 1970s software was basically "open" because it was developed by the scientific research community in which information was generally shared. Software was developed by vendors with the aim of tackling a particular user problem. Afterwards it was freely distributed to other users, generally including the source code. Because software only ran on systems from a single vendor, a good software product could prompt clients to purchase the platform (KAVANAGH 2004: 6).

The concept of proprietary software and software development companies grew in the 1970ies and 1980ies. In 1968 the US American IT and consulting company IBM started to separate software and hardware. The development of competing software development companies and the use of high-level programming languages supported the idea that software should be protected. In 1976 Bill GATES wrote the "*Open Letter to Hobbyists"* in which he criticizes copyright infringements of the hobbyist community as they would cause restrains of developers to invest in the creation of quality software (HOEL et al 2013).
Two years before, in 1974 the *National Commission on New Technological Use of Copyrighted Works CONTU* was established in the USA with the task to evaluate the public protection of software. According to their recommendation, the *Computer Software Copyright Act* which allowed for fees for violations of copyright, was passed in 1980 by Congress. These ideas were adopted in other countries. In the European Union a Guideline for software copyright was introduced in 1991 by the European Commission. It followed the US American idea and classified computer programs as "works of literature" and thus protected their copyright for almost 50 years (RENNERT 2000: 46-47).

Parallel to these developments in the field of commercial software there had always been tendencies to share and collectively improve software code since the beginning of software development. The idea and arguments for OSS were first published by the US American software developer and software freedom activist Richard STALLMAN in 1984 (KAVANAGH 2004: 2). In 1985 he founded the nonprofit organization *Free Software Foundation* (FSF) of which he is president. The organization has the aim to promote the development and use of free software (FSF INC. 2014). According to FSF the idea behind free software is that of a society having control over the technology it uses. The availability of the software's source code is a precondition for this. In the organization's eyes, the transparency of freely accessible source code makes it harder for internet and telecommunications companies or governments to collect private data. The word “free” does not refer to “free of charge” but “user’s freedom”. The matter of free software is perceived as an ideological question; “*“free software” is a matter of liberty, not price*” (FSF INC. 2014). According to the FSF the four criteria for free software are:

- The freedom to run the program, for any purpose (freedom 0).
- The freedom to study how the program works, and change it so it does your computing as you wish (freedom 1). [...]
- The freedom to redistribute copies so you can help your neighbor (freedom 2).
- The freedom to distribute copies of your modified versions to others (freedom 3) [...] (FSF INC. 2014)

At the same time, there were also other representatives in the free software movement for whom the promotion of free software was not an ideological question but a pragmatic one. Thus the *Open Source Initiative* (OSI) was founded in 1998 in California as a public benefit corporation. They introduced the term “open source” (OS) in 1997 for their goal to support the development and distribution of non commercial software (OSI 2014). The organization decided to emphasize technical and practical advantages of open source software (KAVANAGH 2014: 2). The Open Source Definition (OSD) was originally written by Bruce PERENS for the OS operating system *Debian-GNU/Linux* and was completed in 1997 (KAVANAGH 2004: 1). According to OSI, OSS encompasses a list of ten criteria:

1. Free Redistribution
2. Source Code must be included in the program
3. The license must allow modifications and derived works
4. The integrity of the author’s source code
5. No discrimination against persons or groups
6. No discrimination against fields of endeavor
7. The distribution of license
8. The license must not be specific to a product
9. The license must not restrict other software
10. The license must be technology-neutral (OSI 2014)

From the OSI’s perspective “[t]*he two definitions lead to the same result in practice, but use superficially different language to get there*” (OSI 2014). Consequently “free software” and “open source software” are two terms which both describe the same idea of software which is released with an open source code under licenses that enable specific freedoms which should be promoted for different reasons. In this thesis the term “open source software” (OSS) will be used as the comparison of the software ArcGIS and QGIS has pragmatic reasons rather than ideological ones and the author sees this approach to be better reflected through the ideas of OSS.
It took until the late 1990s for the ideas of OSS to become of public interest. This was for instance reflected in articles about the open source operating system *Linux* in publications like the worldwide popular American business magazine *Forbes* (OSI 2014). Another important milestone was the announcement of the software company *Netscape Communications* on January 22nd 1998 to publish their browser’s source code freely on the internet in order to encourage enthusiastic programmers to contribute to the development of their internet browser (MOZILLA 2014).

3.2 Open Source and Open Source Data Formats

Today examples for successful OSS are *Apache Web server*, *Linux* Operating System or GNU C/C++ language suite (KAVANAGH 2004: 3). So far, the success of OSS exists especially in the field of webservers and servers, and less in desktop programs (MENDES 2004: 30). Nevertheless, the market share of OS products is constantly growing. In 2010 a survey was conducted in 2.300 companies in 15 countries which showed that more than 25% of the surveyed firms develop PCSS as well as OSS (LERNER & SCHANKERMAN 2010).
There are more and more institutions that organize and promote OSS and OS Data Formats. In the area of geospatial software the *Open Source Geospatial Foundation* (OSGeo) can be named. It was founded in 2006 in Chicago and represents an international non-profit organization with the aim of supporting open source geospatial software's development and distribution. It is an independent legal entity securing public access to software code. OSGeo contributes to the improvement of cross-project collaborations and promotes the implementation of open standards (OSGeo 2014). Moreover, the *Open Geospatial Consortium* (OGC) which was founded in 1994 as *Open GIS Consortium* needs to be mentioned in this context. It is an international industry consortium consisting of 479 companies, government agencies and universities which work collectively on the development of publicly available interface standards *OGC (R)*. Building on these standards enables technology developers to integrate spatial information and services in different applications (OGC 2014).

Regarding open data formats *GDAL/ORG library* is an important feature. GDAL is an open source translator library licensed by OSGeo for raster geospatial data formats. The GDAL library presents "*a single raster abstract data model and vector abstract data model to the calling application for all supported formats"* (GDAL 1014). Furthermore the library contains several commandline utilities for the purpose of data translation and processing. OGR is a part of the GDAL library. It is a C++ library including commandline tools which provides access to different vector file formats including ESRI Shapefiles, S-57, SDTS, PostGIS, Oracle Spatial or TAB formats (GDAL 1014).
In the field of OS databases *PostgreSQL & PostGIS* need to be mentioned. PostgreSQL is a popular open source object-relational database system operating on Linux, UNIX and Windows. It is fully ACID compliant, has full support for foreign keys, joins, views and triggers as well as stored procedures. Furthermore it includes most SQL:2008 data types and supports storage of binary large objects. Moreover PosgreeSQL contains native programming interfaces for C/C++, Java, Python, ODBC, and others (THE POSTGRESQL GLOBAL DEVELOPMENT GROUP 2014). PostGIS represents an extension for the PostgreSQL database which contains support for geographic objects like running location queries in SQL, Oracle Locator/Spatial and SQL Server (POSTGIS PROJECT STEERING COMMITTEE 2014).

3.3 Advantages and Challenges of OSS and PCSS

OSI promotes OSS development as "*a development method for software that harnesses the power of distributed peer review and transparency of process. The promise of open source is better quality, higher reliability, more flexibility, lower cost, and an end to predatory vendor lock-in*" (OSI 2014). However, "[i]*t is important for managers responsible for* *adopting technology to be fully aware of the issues that open source represents to their organization*" (KAVANAGH 2004: XVII).

Concerning software quality, it is argued that OSS has a higher quality than PCSS due to the nature of its development process. PCSS development creates software with a secret source code that was written with the exclusive knowledge of the company's employees. The programmers follow a goal that was defined by software architects. Before the software is released, it is tested in order to meet the initial goals and quality standards. In comparison to that approach, OSS is developed not only by a coordinating organization, but also by voluntary programmers worldwide. The first version of the software is generally developed similar to the PCSS approach. After its release including the open source code, the users are encouraged to report bugs, ask for new features and tools, or program them on their own. Consequently, in OSS development contributors are often not based in same geographical location. This requires different working mechanisms in which source code has to be shared with several users (ALEXY ET AL 2013: 1326). In this way, OSS development process profits from the knowledge and skills of experts worldwide compared to those of a limited group of software developers working for a single company (KAVANAGH 2004: 41-52). This idea is described in the so called *Linus law* which was formulated by the American programmer RAYMOND. It is named after the Finish American software engineer Linus TORVALDS, leader of the operating system project *Linux kernel*, who invented the process of developing software publicly via the internet in 1991. It refers to the circumstance that bugs and security issues can be discovered and solved more effectively by a large group of beta testers and co-developers (RAYMOND 2001). As an example for this process the famous bug CVE-2014-0160, which became public under the name *heartbleed* should be mentioned. It caused vulnerability in the popular OSS library OpenSSL, resulting in the possibility of theft of protected information without leaving any trace. The bug affected two versions, 1.0.1 and 1.0.2-beta releases of OpenSSL. It was discovered after two years independently by Neel MEHTA of *Google* Security and a team of security engineers at the computer security company *Codenomicon* in April 2014 due to the openness of the source code (CODENOMICON 2014).

Another point that is stressed by supporters of OSS is their potential for faster innovations and update cycles. In some cases OSS is more advanced because innovations can quickly be distributed via the internet instead of including them in the next software release. This applies to new tools as well as to bug fixing.

Furthermore, OSS products make users independent from commercial developers and traders and their product cycles and specific formats. This became visible when *Microsoft Corporation* stopped the support for the widely distributed products *Windows XP* operating system and *Microsoft Office 2003* software on April 8th 2014. According to the company, the use of the products beyond this date would carry "serious risks" (MICROSOFT 2014) for instance concerning security and compatibility, including software problems, the lack of contact persons for technical support as well as more frequent system errors (MICROSOFT 2014). These conditions obliged private users and companies to update their systems which required time and financial resources. Another issue concerns proprietary information formats which contribute to the vendor lock-in. OSS products typically use standard formats. These allow the integration between different software products and use an international context (KAVANAGH 2004: 41-52). In addition, it is possible to make individual adaptations and advancements in OSS as the source code is openly available. Nevertheless these adoptions require programming skills.

A characteristic of OSS is the fact that it is free of charge compared to PCSS. Thus software licensing costs and efforts can be reduced (KAVANAGH 2004: 41-52). Anyhow, it needs to be considered that the costs for using OSS are not limited to the software license itself. Further costs emerge from the required hardware, training for employees, and support (MENDES 2004: 30-31). Depending on the global distribution of the software it might also be the case that it is easier to find trained employees for popular PCSS products. Thus additional time and costs for OSS training are needed. Additionally, PCSS products usually have well developed support infrastructure which can be essential for companies when it comes to meeting a deadline. Furthermore, “business is not always about saving money, it is often about reducing financial RISK” (DUGGAN 2013). In case of software problems and failures which can lead to the non-compliance of a contract, a PCSS product generally comes with insurance.

To summarize the advantages and challenges of OSS products, one can state that *“[n]ot everyone can necessarily benefit by adopting these products [OSS] today. Some may have sunk costs in existing solutions, and there can be large transitional costs in other cases. But open source solutions are sufficiently compelling that every organization should be looking at them as possibilities now*” (KAVANAGH 2004: 40).

4 Software Quality and Evaluation Methods

In this chapter the definition of software quality and its attributes, as well as defects and software testing will be presented. Furthermore, ways of measuring software quality will also be discussed.

4.1 Software Quality Attributes

The term *software quality* describes "the totality of functionality and features of a software product that bear on its ability to satisfy stated or implied needs" (GTB 2013). According to the International Organization for Standardization's norm *ISO/IEC 9126: Information Technology Software Product Evaluation Quality characteristics and guidelines for their use – 1991* software quality attributes consists of the six characteristics *functionality, reliability, usability, efficiency, maintainability,* and *portability* (GTB 2013).

Functionality	**Reliability**	**Usability**
• Suitability • Accuracy • Interoperability • Security • Compliance	• Maturity • Fault tolerance • Recoverability	• Understandability • Learnability • Operability
Efficiency	**Maintainability**	**Portability**
• Time • Resources	• Analyzability • Stability • Testability • Changeability	• Adaptability • Installability • Compliance • Replaceability

Table 1 Software Quality Attributes according to ISO/IEC 9126

Functionality is the "capacity of the software product to provide functions which meet stated and implied needs when the software is used under specified conditions" (GTB 2013). It summarizes all characteristics which describe the required abilities of the software. These abilities are described through their input/output properties and/or a specific reaction to a command. Thus functionality exists if the required ability was realized appropriately. According to ISO 9126 functionality contains the five sub-characteristics *suitability, accuracy, interoperability, security,* and *compliance*. Suitability describes the "capacity of the software product to provide an appropriate set of functions for specified tasks and user objectives (GTB 2013)". Accuracy is the "capability of the software product to provide the correct or agreed results or effects with the needed degree of precision" (GTB 2013). Interoperability is defined as the "capacity of the software to interact with one or more specified components or systems (GTB 2013)". Security consists of the "[a]ttributes of software that bear on its ability to prevent unauthorized access, whether accidental or deliberate, to programs and data (GTB 2013)". Compliance is the "capability of the software product to adhere to standards, conventions or regulations in laws and similar prescriptions" (GTB 2013).

The second quality attribute **reliability** describes the software's ability "to perform its required functions under stated conditions for a specified period of time, or for a specified number of operations" (GTB 2013). Reliability is again composed of the three aspects *maturity, fault tolerance,* and *recoverability*. The sub-characteristic *maturity* is the software's capacity "to avoid failure as a result of defects in the software." Thus it measures the number of failures during a calculation process. Second, the criteria *fault tolerance* defines the capacity of the software "to maintain a specified level of performance in case of software faults (defects) or of infringement of its specified interface" (GTB 2013). Finally the criteria *recoverability* characterizes the software's capacity "to re-establish a specified level of performance and recover the data directly affected in case of failure" (GTB 2013). To do so, the required time and effort need to be evaluated.

The third major quality attribute **usability** measures the effort necessary for the software's handling for a specific user group. Software usability is defined in specific as the capability of a software product "to be understood, learned, used, and attractive to the user, when used under specified conditions" (GTB 2013). It includes the three components *understandability, learnability,* and *operability* as well as aspects like the satisfaction concerning standards, conventions, and style guides. The first component *understandability* defines the capability of the software "to enable the user to understand whether the software is suitable, and how it can be used for particular tasks and conditions of use." *Learnability* describes the software's capability "to enable the user to learn its application" (GTB 2013). This aspect also includes mainly the availability and quality of documentation. Concerning learning the concept of the learning curve**,** a graphic representation of the increase of learning (vertical axis) over time/ with experience (horizontal axis) can be used. A steep learning curve represents a difficult initial learning process while a shallow curve describes an easy learning process.

Finally, *operability* describes the "capacity of the software product to enable the user to operate and control it" (GTB 2013). Consequently it deals with the software's handling.

The fourth quality attribute **efficiency** describes the time and resources that are needed to fulfill a specific task. The resources include other software or the system configuration. Thus efficiency can be summarized as the software's capability "to provide appropriate performance, relative to the amount of resources used under stated conditions" (GTB 2013). In distinction to the other quality attributes efficiency is easier to measure with a metric scale and thus it does not need further sub-criteria.

The fifth quality attribute **maintainability** means on the one hand that the software can be analyzed and modified, and on the other that it's stable and testable. It is defined as the "ease with which a software product can be modified to correct defects, modified to meet new requirements, modified to make future maintenance easier, or adapted to a changed environment" (GTB 2013). Just like the other quality attributes maintainability holds a set of sub-characteristics that describe it in more detail. Those are *analyzability*, *stability, testability* and *changeability*. Analyzability characterizes the software's capacity "to be diagnosed for deficiencies or causes of failure in the software, or for the parts to be modified to be identified." Consequently, the software's openness of the source code plays a crucial role. The next criteria, stability describes the "capacity of the software product to avoid unexpected effects from modifications in the software" (GTB 2013). Testability is the software's capability "to enable modified software to be tested" (GTB 2013). Finally changeability characterizes the software's capacity "to enable specified modifications to be implemented".

Maintainability is closely connected to portability. **Portability** refers to the characteristics of being able to adapt and install the software as well its conformity exchangeability. It is defined as the "ease with which the software product can be transferred from one hardware or software environment to another" (GTB 2013). Portability is characterized by the sub-criteria *adaptability, installability, compliance* and *replaceability*. Adaptability refers to the capacity of the software product "to be adapted for different specified environments without applying actions or means other than those provided for this purpose for the software considered" (GTB 2013). It is closely connected to the attribute installability, which is the software's capability "to be installed in a specified environment" (GTB 2013). Compliance characterizes the software's capacity "to adhere to standards, conventions or regulations in laws and similar prescriptions" while replaceability defines the capacity of the software product "to be used in place of another specified software product for the same purpose in the same environment" (GTB 2013). The majority of maintainability and portability aspects can only be tested with the help of static analysis.

In order to evaluate the software quality, all of the described attributes have to be considered. In general, a software system cannot fulfill all quality attributes in the same way. In some cases the single quality attributes exclude each other and the manifestation of one criterion will weaken another one. For instance a highly efficient software system is usually only portable to a certain degree because the developers use specific characteristics of the platform to increase its efficiency which have negative effects concerning the software's portability. Consequently it is necessary to set priorities with regard to the specific attributes (SPILLNER & LINZ 2012: 11ff & GTB 2013).

4.2 Defects and Software Testing

In the same way as software quality can be defined, there are also clear definitions for the failure of software systems. Failures in software don't appear over time like in physical objects as result of deterioration, but they exist since the initial development of the software. When using the software a *failure* becomes visible, for instance wrong output, or the program crashes. A failure is defined as "a deviation of the component or system from its expected delivery, service, or result" (GTB 2013). However, a failure needs to be distinguished from its origin which is a *fault*. Thus failures are the result of faults in the software. This condition is also known as a *defect* or a *bug, "*a flaw in a component or system that can cause the component or system to fail to perform its required function, e.g. an incorrect statement or data definition*"* (GTB 2013). As an example a programming mistake or the absence of an instruction can be named. The origin of a defect again is an incorrect action of a human being for instance a software developer's incorrect programming. This circumstance is defined as an *error* (SPILLNER & LINZ 2012: 8). Defects have different manifestations regarding their severity. In the reviewing processes four categories for the categorization of defects are used. *Good* indicates no defects. *Minor defects* are small deviations which hardly reduce the usability such as for instance spelling mistakes. The category *major defect* stands for defects that harm the usability of the object, and *critical defects* state that the feature is not adequate to perform its intended aim (SPILLNER & LINZ 2012: 87).

In order to avoid defects in software, testing is part of a software development process. The aim of testing is the proof for the set requirements' compliance and the revealing of potential defects (SPILLNER & LINZ 2012: 110). There are several software testing methods to be distinguished. One way is to differentiate between static and dynamic testing. *Dynamic Testing* is "testing that involves the execution of the software of the component or system" (GTB 2013). The tested object is provided with input data and subsequently executed. The tested object will generally activate other software components. In order to implement a test, the conditions and requirements as well as the aims of the tests need to be defined. Furthermore the single test cases need to be specified and test implementation has to be set (SPILLNER & LINZ 2012: 110). In contrast to dynamic testing, *static testing* is "testing of a software development artifact, e.g. requirements, design or code, without execution of these artifacts, e.g. reviews or static analysis (GTB 2013)." Another widely used method is *stress testing*, "a type of performance testing conducted to evaluate a system or component at or beyond the limits of its anticipated or specified workloads, or with reduced availability of resources such as access to memory or servers" (GTB 2013). In case of *Checklist-based testing* the tester has a high-level list of items or a set of rules of criteria with which the software is evaluated (GTB 2013).

4.3 Design Principles for Cartographic Applications

A Graphic User Interface (GUI) is an interface with the computer where communication is implemented with the use of graphical elements rather than text as compared to a Command Driven Interface. Thus the GUI in form of a WIMP [windows, icons, menus, pointers] Interface enables an easy and efficient handling for the user (RIEDL 2000). In a WIMP Interface the application is shown in a window. Toolbars with icons or texts enable the access to commonly used functions. Menu options can be selected with the mouse pointer that is controlled by the user and is shown as a symbol on the screen. Furthermore, keyboard shortcuts can provide the functions that could be activated via a click on an icon or command and thus enable experienced users to work faster (JOHNSTONE 2014).

The GUI's design is essential for the application's usability. In modern software usually 50% of the resources are used for the interface's programming (REITERER 1994). As in GIS systems the graphical component plays a crucial role, the principles for the design of cartographic applications will be described in the following section. The aim of a user friendly application is to guarantee that the user has access to the functions and has the feeling that he/she is controlling the software (BAYER 2002).

An easy access to functions can be achieved by **direct manipulation.** This element of interactivity refers to symbols in form of control knobs, switches or icons which can be manipulated directly by the user. The user can always see the results of his/her actions. As the means of manipulation repeat themselves and the handling is easy to understand and can be easily reversed. Additionally, through the use of **symbols**, metaphors, and icons the functionality can easily be decoded by the user. An appropriate metaphor enables the user to draw on existing knowledge about an application's handling without having to go through a learning process. The familiar environment gives the user a feeling of security and control (RIDEL 2000).

Concerning the features **control and stability** the user should have the feeling that he/she is controlling the software and not the other way around. Consequently, there should not be unexpected responses and the provision of sufficient information is essential. Another component of giving the user the feeling of control is the feature that software should give **visual feedback** about its current state of process. This means that the object which is being used at the particular moment is changing its appearance. For instance when hovering over a button or clicking on it its size, color etc. can change, or during a calculation process the progress can be shown in form of a growing scale bar with the reached percent. The **fault tolerance** represents another crucial point. Wrong handling by the user must not cause severe failures. In case of failures, there should be a meaningful message which enables the user to avoid wrong handling in the future. Ideally actions can be revoked. An option for avoiding wrong input is **menu selection.** In this case the user can select from a list of actions which gives the user a choice between all the correct actions. However it is necessary that menu selections do not have too many levels otherwise commands are hard to find or it requires to much time to get there. The fault tolerance is also important for **form fill in** elements which are necessary to proceed data that is entered by the user, for instance for quary building. Due to their nature, they are vulnerable to wrong input and consequently to error messages. The tolerance level concerning inexact input is a measure for its usability (RIEDL 2000).

Another criterion for a user friendly interface is **consistency**. Consistency is defined as the "degree of uniformity, standardization, and freedom from contradiction among the documents or parts of a component or system" (GTB 2013). In case of GIS software, graphic elements and their functions should be used in the same manner for the complete software. Moreover, information needs to be organized and presented according to principles of cartographic design. These include consistent layout, color, font, size, transparency, or symbols.

After having presented software quality attributes, this section will approach ways to evaluate software quality and functions. Comparing various GIS software is a very complex task as they differ in native forms and processing of spatial data and sets of GIS functions (DOBESOVA 2013). Furthermore the software selection process consists of measurable as well as non measurable aspects which makes their prioritization difficult (ZAHEDI ET AL 2011). Consequently different evaluation methods will be examined in order to identify the strength of the particular methods which will best suit the planned software comparison of ArcGIS and QGIS. The presented evaluation methods include Goal-Question-Metric method (GQM), Analytic Hierarchy Process (AHP) and CartoEvaluation Method.

4.4 Goal-Question-Metric Method [GQM]

GQM method was designed by BASILI in the 1990s at University of Maryland, College Park and in Software Engineering Laboratory in Goddard Space Flight Centre NASA. Initially it was used to evaluate defects for specific projects, whereas today the method is applicable for multipurpose evaluation of software (BASILI ET AL 1994). GQM is "*an established and elaborated method for measurement in software engineering*" (BIRK 2010). It is for instance applied by NASA, Hewlett Packard, Motorola, and Coopers & Lybrand. The principle of the method is the identification of main tasks, so called "goals" the specific software should perform. The result of the Goal Question Metric application is the creation of a measurement system consisting of three levels, the conceptual, operational and quantitative level (BASILI ET AL 1994).

On the first level, the **conceptual level**, a "goal is defined for an object, for a variety of reasons, with respect to various models of quality, from various points of view, relative to a particular environment" (BASILI ET AL. 1994: 3). These objects of measurement can be products, processes, or resources. Products are "artifacts, deliverables, and documents that are produced during the system life cycle" (ebenda). Processes represent "software related activities normally associated with time" (ebenda) and resources refer to "items used by processes in order to produce their outputs, e.g. personnel, hardware, software…"(ebenda). The success of GQM is closely related to the goal setting process. As a result the process is implemented with the help of specific methodological steps. Thus a goal includes the three coordinates *Issue*, *Object/Process,* and *Viewpoint* as well as a *Purpose*. While specifying the goals the corresponding organization's structure and policy should be considered.

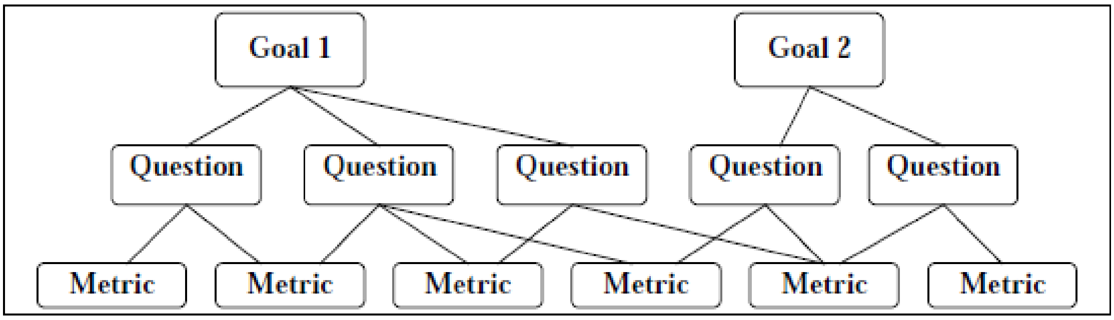


Figure 3 Structure of GQM Model, Source: BASILI ET AL 1994

On the second level, the **operational level**, a set of questions is developed with the aim of characterizing the assessment of a specific goal. These questions try to characterize the object of measurement [product, process, resource] with respect to a selected quality issue and to determine its quality from the selected viewpoint. For the generation of question three different kinds of questions should be asked. The first aspect covers the characterization of the object with regard to the goal, second highlights the object's attributes, and the third aspect concerns the evaluation of the object's relevant characteristics. In the last step, the **quantitative level** for each question a metric scale will be generated. The scale can be objective, for instance numbers, hours, size, etc. or subjective, like the level of user satisfaction. Generally objective measures are used with respect to mature measurement objects while subject evaluations are applied for informal or unstable objects. Furthermore it is suggested to use only a single level of metrics. In case of more complex metrics, it is necessary to apply more precise definitions. Moreover it is possible to use the same metric for answering different questions. Additionally several GQM models can include the same questions with different measurement scales as they might represent different viewpoints that judge the importance of the criteria individually. When the metrics for the questions are created the amount and quality of the existing data should be considered. Finally one needs to remember that the development of metrics is not a linear process. Instead, GQM models need refinement and adaption (BASILI ET AL 1994). Due to this approach, Goal-Question-Metric Method is appropriate for the systematic definition of a software measurement system as well as for evaluation of software projects (BIRK 2010).

4.5 Analytical Hierarchy Process [AHP]

AHP was designed in the 1970ies by the US American mathematician SAATY for rational decision making on complex issues. It combines the deductive and the systems approach to decision making and thus includes single parts as well as the way in which they work together as a whole. AHP is a flexible model for multiple criteria decisions that require more than one scale of measurement. The aim is to simplify and accelerate the user's decision-making-process. This can be achieved through disassembling a complex, unstructured topic to its components. These components or variables are then ordered in a hierarchical manner by translating subjective judgments concerning their importance into numerical values. AHP follows the three principles of analytic thought: structuring hierarchies, setting priorities, and logical consistency. The principle of structuring hierarchies refers to the procedure of the human mind to structure complex realities into homogeneous clusters that usually range between five and nine. Setting priorities is undertaken by humans through the understanding of relationships between features. They compare them and discriminate between pairs by judging the intensity of their preference. The principle of logical consistency contains two elements. First, similar objects are grouped according to homogeneity and relevance, and second the intensities of relations between objects justify each other in a logical way (SAATY 1995: 5ff). AHP consists of three steps. The first step is decomposition in which a problem is structured into a hierarchy which is built of a goal and subordinated features. In the second step, the evaluation presents pair-wise comparisons between elements at each level. The third step, the synthesis, lies in the transmission of level specific priorities to general priorities (SCHMOLD ET AL 2001).

When defining the hierarchy, the first step lies in the definition of a single overall goal. This is called *first hierarchy* or *focus*. The next few hierarchy levels each consist of several elements. The necessary number of hierarchies is reached when elements on the same level are directly comparable, otherwise a finer distinction is required. When the data hierarchy is defined, pair wise comparison matrices will be created. These matrices represent the specific element's relevance or impact for each governing criterion of the next higher level. The comparison can be judged by preference, importance or likelihood depending on the context. Measurement is generally done with numbers because they can represent variations of judgments more accurately than words. When comparing two elements the dominance of one is indicated with a whole number. The values in the matrix thus show the dominance of an element placed in the row over an element in the column. Additionally the reciprocal will be added at a specific position in the matrix. Elements on the diagonal are always 1. The measurement scale consists of 9 levels, 5 basis levels and 4 intermediate levels.

Intensity of Importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong or demonstrated importance
9	Extreme importance
2,4,6,8	*For comparison between the above values*

Table 2 Measurement Scale for AHP, Source: SAATY 1995: 73

The normalized principal right eigenvector of the matrix indicates the criteria's priority values. This judgment is implemented for all levels and clusters in the hierarchy. Each element in the row has a priority which is indicated as a percentage. All elements of a hierarchy add up to 100 percent.

Option 1	Element 1	Element 2	Element 3	Weight
Element 1	1	5	7	73%
Element 2	1/5	1	2	16%
Element 3	1/7	1/2	1	1%

Table 3 AHP Matrix, Source: Own Example after SAATY 1995

The vectors of priority are weighed by weight of the criteria. The final result of the AHP will be a numerical value for each alternative while the highest score represents the most adequate solution (SAATY 1995).

AHP is used in various fields including in practical and academic contexts (SCHMOLD ET AL 2001: 6ff). It is widely applied in the Anglo-American and Asian territory and has a high potential for further use due to its high flexibility and systematic approach to decision making (MEIXNER & HAAS 2010: 169).

4.6 CartoEvaluation Method

This method was developed for the evaluation of Desktop GIS software in 2008 within the project "Evaluation of cartographic functionality in GIS software" of the Department of Geoinformatics, Palacký University, Olomouc, Czech Republic, the Department of Human Geography and Demogeography, Comenius University, Bratislava, Slovak Republic and Faculty of Science, University of Szeged in Hungary. It aims at evaluating different GIS software with respect to their cartographic functionality and conception of creating thematic map output. It is particularly dedicated to Desktop GIS software (DOBEŠOVÁ ET AL 2008). The theoretical bases for the method are multi criteria evaluation as well as AHP and GQM methods which were explained earlier in this chapter. The aim of multi criteria evaluation is to reveal the best suitable option among a set of options, in case of CartoEvaluation method, the software with the best cartographical possibilities.

Goal		%	Score
A	Map construction	15	15,0
B	Map symbols	35	35,0
C	Cartography methods	35	35,0
D	Map syntax (stratigraphic, componential and compositional)	15	15,0
Total score		100	**100,0**

Figure 4 Main Goals of CartoEvaluation Method and their Weights

Main goal Sub -goal	Weight [%] Sub-goal	Weight [%] Main goal
Map Construction		**15**
Map Outline	3	
Reference System of Map Face	4	
Transformation of map outline	4	
Metadata about map construction	2	
Cartometry	2	
Map Symbols		**35**
Pattern Book	1,5	
Point Symbols	8	
Line Symbols	8	
Area Symbols	8	
Localisation of Map Symbols	3	
Color Setting	6	
Metadata information about symbols	0,5	
Cartographic Methods		**35**
Basic Methods	8	
Mapping Diagrams	8	
Scales of Values	3	
Label	10	
Specific Methods	6	
Map Syntax		**15**
Intracomposition - overall design/ layout of symbols	1,5	
Map Layers	3	
Extra composition - overall graphic arrangement	2	
Basic composition elements - title and colophon	0,5	
Basic composition element - legend	5	
Basic composition element - map scale	1	
Additional composition elements	2	
Total Score	**100**	**100**

Figure 5 Criteria of CartoEvaluation Method, Source: DOBEŠOVÁ 2013

This is done by calculating the weighted sum of all set criteria which will sum up to 100 in case of complete fulfillment of all criteria. Thus it is necessary to set the weights for the single criteria. This process is rather complex because the relative importance of criteria will vary between different users with their particular needs. In CartoEvaluation Method the criteria were weighed by an international group of experts with the help of AHP by pair wise comparison. Furthermore GQM was applied. The 'goal' in the sense of GQM was the key functions which need to be performed for the creation of maps. As a result of the process four main goals and 23 sub goals as well as more than 300 partial goals were defined. The main goals of the CartoEvaluation method in the sense of GQM are Map Construction, Map Symbols, Cartographic Expression Methods, and Map Syntax. The main goals and sub goals including their weights can be viewed in the following chart.

5 Methodology

In order to evaluate whether the OS GIS QGIS can fulfill the tasks of a spatial planning office in the same way as ArcGIS, it is necessary to approach the research question from the angle of a software selection process. Software selection process is a complex process.

"*Software selection is not a technical procedure, but is rather, a subjective and uncertain decision process*" (STAMELOS ET AL 2000).

"*Decision making in the field of software selection has become more complex due to […] ongoing improvements in information technology and multiple and sometimes conflicting objectives*" (ZAHEDI ET AL 2011)

"*Software is an intangible product that is not always conducive to explicit acceptance measures*" (ZRYMIAK 2010).

"*Software selection decisions include tangible and intangible factors; so prioritizing these factors can be challenging*" (ZAHEDI ET AL 2011).

These quotes make clear, that a software selection process involves various factors, which are sometimes hard to measure and thus to prioritize. The factors for software selection on the one hand include measurable aspects, like a calculation process's speed or the software's price. On the other hand, there are aspects that cannot or can only vaguely be measured like the GUI's user-friendliness. Furthermore the perceived importance of these factors will vary according to the planning office's needs.

For these reasons **method triangulation** will be applied to answer the research questions because each method focuses on a different research object. Thus, restrictions of single methods can be compensated. The approach will contain qualitative and quantitative research methods to be able to examine objectively measurable quantitative aspects, as well as subjective qualitative aspects that are harder to grasp (Cf. FLICK 1998). The applied methods encompass discourse analysis, an expert interview, CartoEvaluation Method, and GIS test analyses which will be measured with the help of GQM and AHP.

Spatial planning offices use a broad range of GIS functionality depending on their professional focus and accordingly not all of them can be investigated within the framework of this thesis. Consequently it is unavoidable to draw up a short list. The selected aspects that will be evaluated in this thesis compound general ones that are valid for each planning office working with GIS as well as specific ones that are only applied by certain planning offices that focus on sustainable development. According to the research question, the comparison will consist of the three categories, "Parameters", "Structure and Functionality", as well as "Software Quality". The comparison of ***parameters*** as well as ***structure*** and ***functionality*** of the two GIS software includes general GIS tasks and frameworks which are not specifically connected to a specific spatial planning office but is valid for planning offices with different specializations. These include for instance the software's distribution, the availability of trainings and learning material, data formats and management, or data visualization. Due to the fact that the importance of these aspects varies from office to office an evaluation, which contains the determination of the criteria's weights via GQM and AHP will not be applied. This would conflict with the aim of the thesis which is not to examine which software is better in general, but to compare certain features concerning their sufficiency for spatial planning tasks. Furthermore, diverse user groups will classify different criteria with different values as important. Each planning office will consider different criteria relevant which are dependent on the office's tasks.

For the third category, the **software quality,** specific test analyses in the field of sustainable spatial planning are implemented based on the theory. For the spatial analysis Open Government Data on European, Regional, and City Level will be used. For the investigation of Quality Attributes the definition of the International Organization for Standardization's norm *ISO/IEC 9126* will be applied. In order to measure and rank the GIS software's quality attributes, Goal-Question-Metric Method (GQM) and Analytical Hierarchy Process (AHP) are combined.

The evaluated ArcGIS software version is ArcGIS 10.2.2 for Desktop. Due to the fact, that QGIS has a short release cycle of fourth month, the versions 2.4 and 2.6 (2.5 is the developer version) were used. The test analysis were run with QGIS 2.4, the results are valid for 2.6 though too, because none of the used tools changed in their functionality or settings. For the parameters as well as the software structure and functionality the features of QGIS 2.6 were evaluated.

5.1 Discourse Analysis

AIM & SAMPLE

As there is no literature about the comparative use of GIS software in spatial planning, a discourse analysis of online forums and blog articles will be performed. It aims at identifying elements in which ArcGIS and QGIS show similarities and differences. The second goal is descriptive research and thus the estimation of the differences' frequencies (DIEKMAN 2010).

For the research on the web the words "ArcGIS" and "QGIS" were searched with the search engines *Google* and *Ecosia*. As QGIS is developing very rapidly with approximately one new release every four months, the date of the discussion and the corresponding QGIS version has to be taken into consideration. Only comments later than 2011 were analyzed. Two of the selected discussions are not specifically dedicated to ArcGIS and QGIS but to commercial and open source GIS software. Despite this fact, they will be analyzed with respect to the two investigated software. In order to minimize ideological statements only websites with comments from GIS professionals were considered.

The search brought up the following topics in forums and blogs that contain a comparison of ArcGIS and QGIS respectively open source and proprietary GIS software:

- *"What are the differences between the capabilities of QGIS and ArcGIS?"* [GIS STACK EXCHANGE, Oct 2012]
- *"What are data visualization and analyses pros/cons of QGIS over ArcGIS?"* [GIS STACK EXCHANGE, Feb 2012]
- *"Should we choose open-source GIS softwares [sic] or the commercial ones?"* [researchgate, Oct 2012-Dec 2013]
- *"QGIS Versus ArcGIS by Category"* [GIS LOUNGE, Nov 2012]

- *"Open Source and Proprietary #GIS software – the eternal debate"* [The Spatial Blog, Nov 2013]
- *"Is QGIS a viable alternative to ArcGIS?"* [Don Meltz – Planning and GIS, June 2011]

In the context of the research method discourse analysis the content of the texts cannot be viewed without considering the conditions in which they were written. Consequently it is necessary to analyze the contexts of the websites and blogs. The interpretation of the institutional framework consists of the type of publication, the context in which the text was written, as well as the author's background (ANGERMÜLLER 2001).

The website ***Geographic Information Systems Stack Exchange*** [http://gis.stackexchange.com] is a question and answer site for cartographers, geographers and GIS professionals. The website does not require registration. However there is a quality control integrated through the way the website works. Users can rate answers and thus good ones will rise to the top, and bad ones to the bottom. In addition registered users will get scores depending on their comment's ratings (STACK EXCHANGE INC. 2014).

Research Gate [http://www.researchgate.net/] is a platform for international scientists who are registered with a profile including their names and institutes and where they can publish their research (RESEARCHGATE 2014). Consequently one can assume higher quality of the comment's contents.

GIS Lounge [http://www.gislounge.com/]is an information portal with a focus on geographic information systems. The site aims at providing articles on GIS topics and other resources for the geospatial field. The cited article is written by Caitlin DEMPSEY who is the portals' editor and additionally is owner of the consulting firm *DM Geographics, LLC* which classifies her as a GIS expert (GIS LOUNGE 2014)

The Spatial Blog [http://dragons8mycat.wordpress.com/] is run by the GIS consultant Nicholas DUGGAN whose aim is to mediate GIS issues between different disciplines. He has 15 years of experience in the field of GIS and works as a consultant for one of the UK's largest Renewable Energy consultancies, *TUV SUD PMSS* (DUGGAN 2014).

Don Meltz planning and GIS [http://www.donmeltz.com/] is an independent planning consulting firm which is owned and operated by Don MELTZ, AICP. As a planning consultant specialized in GIS he develops strategies with government officials and residents of small towns and rural areas. He uses ArcGIS and QGIS simultaneously according to their suitability (MELTZ 2014).

IMPLEMENTATION

The user comments are analyzed according to quantitative and qualitative criteria. First, they are filtered for those with a relevant content, meaning that the comment refers to the question. Afterwards the comments will be arranged into classes that describe the differences and similarities of the programs. The categories were formed by means of a hermeneutic approach. Thus they were first created with the aid of literature research and subsequently were adapted when the discourse analysis was applied.

The final categories are:

- Development & Distribution
- Costs & Licenses
- Support
- Data Management
- Mapping & Visualization
- Editing
- Geoprocessing
- Spatial Analysis
- User Specific
- Usability
- Efficiency
- Portability
- Reliability
- Accuracy

The category “User Specific” is for comments stating that the software has to be chosen according to the user’s abilities or the specific task.

While categorizing the statement the following rules will be applied:

- One comment can be divided into several categories.
- One comment can be divided into several aspects per category.
- Comments that get overall negative ratings from blog users are not taken into account.
- Comments which do not refer to the question but for instance different software or general differences between open source and proprietary software will not be considered.
- No comments that state the personal preference of users will be taken into account unlike when they refer to a specific quality attribute.

As a result, there will be a histogram with the frequency of the comments per category, and a qualitative summary of the comment’s content per category.

EVALUATION

In total 33 comments with useful content were divided into 122 aspects in the 14 categories. Generally there were hardly any comments with irrelevant or judgmental content, and the posts uphold a professional level.

The Discourse Analysis revealed where GIS users see the major differences of ArcGIS and QGIS. In *Research Gate* the question was not dedicated specifically to ArcGIS and QGIS but to open and commercial GIS software. Anyhow commercial software was put on the same level as ArcGIS in the discussion. For open source software the comments did not just include QGIS but also other open source GIS. Nevertheless, they referred mostly to QGIS and GRASS GIS. As GRASS tools are available through QGIS GUI these comments could be used anyway.

5.2 Expert Interview

AIM & SAMPLE

The expert interview aims at finding out about fields in which ArcGIS and QGIS show relevant differences. Furthermore the idea is to gain more background information about developments within the OS GIS community. As expert FINK, Phd Student in GI Science at the University Salzburg, lecturer for the class "Open GIS and Open Data" at the University of Vienna was interviewed on Fr, May 23rd 2014.

IMPLEMENTATION

The interview was conducted as a guideline based interview. Thus a list of questions and topics that needed to covered was prepared. However there was also space for unexpected information. While evaluating the interview the objectivity of the expert has to be considered as member of the open source GIS community and thus biased to a certain extent. The interviews were recorded and transcribed content wise as no linguistic analysis is needed (DIEKMAN 2010). The interview was conducted in English.

The expert was asked questions on the field of open source and proprietary software, differences of ArcGIS and QGIS and quality attributes as well as current and future trends in GIS. The interviewee was asked on the differences between ArcGIS and QGIS as open questions instead of category wise in order to see where the expert set his priorities.

EVALUATION

The interview was balanced between keeping to the interview guidelines and leaving space for upcoming topics. All questions of the interview guideline could be covered. With a duration of 80 minutes, the interview was rather long but also involved topics out of the guidelines as well as follow up questions that led to detailed information. No personal opinions were mentioned in order to give the interviewee space for his thoughts. The interview was recorded to be able to focus on the content of the interview. Despite the conduction of construction works at some point during the interview, all the content could be understood clearly on the dictaphone. The interview was transcribed soon after its conduction, so the content was still present.

5.3 CartoEvaluation Method

AIM & IMPLEMENTATION

The presentation of data in maps is a general task which is applied in all planning offices. Both GIS provide a wide range of functionality in this field. Therefore CartoEvaluation Method will be applied. The researchers who created the CartoEvaluation Method provide a *Microsoft Excel 2003* file on the project homepage (http://www.geoinformatics.upol.cz/app/visegrad/images/CartoEvaluation.zip) including the criteria and weights, so that users can apply the method for new GIS versions independently. Although the evaluation schema was developed in 2009 the evaluation catalog is still up to date because it includes features that cover the latest cartographic methods for instance animated maps and symbols, visualization of 3D surfaces or visualization of spatio-temporal data. Consequently CartoEvaluation Method was applied for ArcGIS 10.2.2 and QGIS 2.6. The full evaluation catalogue can be found in the Annex. The test results from 2009 were taken as the basis for the evaluation. Then the questions that were answered with "no" were examined to whether or not the functionality exists meanwhile.

EVALUATION

In the first place, questions were answered by looking for the functions in the software. In case they could not be found, additional research in the GIS manuals and the internet was conducted. Nevertheless, not all of the questions could be answered with certainty. This was mainly due to the fact that the question's target could not be fully understood because the explanations were too short or could not be understood linguistically. The latter could sometimes be compensated by translating the original Czech version into English and the German language in the online translator *Google Translate*. In cases where the answer was uncertain, the value was set to zero respective to the fact that the functionality does not exist and the question was marked with white color. Aspects that did not change since 2009 are marked yellow while aspects that changed are highlighted in orange.

5.4 Test Analyses

AIM & TEST SCENARIO

The aim of the test analysis is to compare the software quality attributes of ArcGIS and QGIS for specific applications in sustainable spatial planning. The test analyses were chosen based on literature research on sustainable spatial planning. As indicators for software quality the definition of ISO is used. It includes the following criteria:

- Functionality
- Reliability
- Usability
- Efficiency
- Maintainability & Portability

Concerning the parameter *Usability* it needs to be considered that software is rarely conceived to satisfy the needs of only one homogeneous customer (HERZWURM & SCHOCKERT 2003: 39). However there are several standard principles that will be evaluated. The analysis will be conducted for a user without programming skills. Only the existing functionality of the software will be used.

TEST ANALYSIS:

1. Catchment Area for Green Spaces (Buffer)
2. Density Prognosis with Time Enables Maps
3. Visibility Analysis for Wind Parks
4. Shortest Path Routing for Public Transport, Cars, and Bikers
5. Site Location Search for Solar Panels
6. Findings for Georeferencing and Editing

DATA

In order to avoid license and copyright issues, the analyses conducted in this thesis will be implemented with open data. The geodata will cover different geographical scales so that a higher variety of file sizes and thus processing resources can be achieved. Furthermore raster and vector datasets in different CRS are used. The list of used data can be viewed in the Annex.

TEST ENVIRONMENT

For the purpose of being more easily comparable, all tests will be run with the same hardware, software operating system, and data. The analyses that are conducted in this thesis will be implemented with the following parameters:

Hardware & Operating System

- Windows 7, 64bit on Samsung Q330 laptop, Intel Core i3 CPU, 2.27GHz, 4 GB RAM

Software

- QGIS 2.4 for Windows, 64bit including GRASS GIS 6.4.3 and SAGA GIS 2.0.8
- ArcGIS 10.2.2 for Desktop Advanced [Windows] including the Extensions *Spatial Analyst*, *3D Analyst* and *Network Analyst*, single user license [Student License]

Setup

- If not specified otherwise the following parameters are used:
- Settings: Overwrite geoprocessing outcomes and stores as relative path
- Used geodatabases (ArcGIS: File Geodatabase, QGIS: SpatialLight)

IMPLEMENTATION

In order to evaluate the analysis systematically, **Checklist-based testing** will be applied. Checklist-based testing is “an experience-based test design technique whereby the experienced tester uses a high-level list of items to be […] checked, […] or a set of rules of criteria against which a product has to be verified” (GTB 2013). Thus a question catalog will be created with GQM and AHP method and filled in during the tests in an excel file. The overrated goal “software quality” as defined by ISO is used. Before applying the schema, a pretest will be implemented in order to find missing categories or mistakes in the design.

Moreover the pretest enables one to see possible variations in the answers and to check whether the design works (HÄDER 2006).

Rules for Spatial Analysis

- All tests are run with the same hardware, software, operating system and data sets
- When buffering [*no response*] more than 10min, process will be canceled
- For the case, that a test failed, re-testing will be applied in order to verify the success of corrective actions
- If tools are not sufficiently documented in the official manual, research on the internet will be conducted
- The time for performing an algorithm will be stopped.
- The time for performing an entire analysis cannot be stopped as the working speed cannot be compared objectively.

Troubleshooting

In case of problems the following measures will be applied:

- Check error messages in help/internet
- Adapt Data Quality
- Rerun tool
- Restart software / hardware
- Generate new map document/project/ feature datasets/ geodatabase

Each analysis includes the aspects task, tools, data, data preparation, workflow, results, quality attributes, and further possibilities.

EVALUATION

During the analysis several obstacles had to be overcome. In the beginning overlarge datasets were being used in the beginning and calculation times were extraordinary long. It is debatable whether a laptop is an adequate tool to run GIS software. Moreover, in QGIS there is no documentation of the calculation time of geoprocessing results, thus they had to be stopped with a stopwatch, which is more imprecise. However it turned out that GIS documented calculation time is shorter than when it's stopped, not including the time for the new layer to be added to the display. Generally not all problems were documented as this would go too much into detail. Further, it was hard to compare the outcomes because the parameters algorithms were not always comparable or simply not explained.

For QGIS the analysis were run with the version QGIS 2.4. The results are also valid for QGIS 2.6. It was checked that the tools still have the same settings.

5.5 Goal-Question-Metric Method Application

Because GQM can be used for multipurpose evaluations of software it was selected for use to evaluate the test analyses. The specific goals vary according to the specific analyses and consequently several GQM trees will be created. As the creation of GQM trees is not a linear process, a pretest will be conducted and the measurement system can be adapted according to the needs during the evaluation process. The GQM trees for functionality will differ from analysis to analysis while the GQM trees for reliability, usability, and efficiency will be equivalent.

The *Software Quality* [goal] of QGIS and ArcGIS will be analyzed for the specific applications in the context of sustainable spatial planning as named before. The questions should try to characterize the object of measurement. They will be formulated with the help of ISO's software quality attributes *functionality, reliability, usability, efficiency,* and their sub criteria. Maintainability and portability cannot be included as they are usually evaluated in static testing.

Functionality	**Reliability**	**Usability**	**Efficiency**
• Suitability • Accuracy • Interoperability ~~• Security~~ • Compliance	• Maturity • Fault tolerance ~~• Recoverability~~	• Understandability • Learnability • Operability	• Time • Resources

Security will not be included, because the access to data is not of relevance for a single user Desktop GIS version compared to a server version. Recoverability cannot be measured systematically because it is not possible to produce frequent system failures due to limited hardware resources.

Concerning metrics there are numerical and nominal answers [yes/no]. Moreover it is possible to use the same metric for answering different questions.

Rules for the creation of GQM trees:

- One sub category of quality attributes can be measured though more than one question
- The data can be objective or subjective
- A single level of metrics is used
- In case of complex metrics precise definitions are applied
- The same metric can be used for answering different questions
- Metrics include numerical and nominal answers [yes/no]
- Several GQM models can include the same questions with different measurement scales
- The amount and quality of the existing data is considered
- GQM trees can be redefined and adaption during the test analysis

In the following, the GQM tree for Operability is presented. The remaining GQM trees can be found in the annex.

Goal	Question	Metric
Operability	How many menu sublevels are needed to get to the tool?	0=> 2, 1= ≤2
	Do the programs use unique symbols for the tool's GUI?	0=no, 1=yes
	Are the graphic design elements [colour, size, font, fill, form, direction, transparency] used coherently within all levels?	0=no, 1=yes
	Are there any unexpected responses?	0=no, 1=yes
	Does the tool give visual feedback during the calculation process?	0=no, 1=yes
	Can output be overwritten?	0=no, 1=yes
	Can the action be revoked?	0=no, 1=yes
	If a new layer is created, can it automatically be added to the TOC?	0=no, 1=yes
	Are plugins/extensions already activated?	0=no, 1=yes

Table 4 QGM tree for Operability

5.6 Analytical Hierarchy Process [AHP] Application

With the help of GQM the relevant factors for comparison could be identified and systematically itemized. However, the criteria have not been prioritized yet and none of the software had been judged to be more appropriate for a specific task.

> "*In general, decision-making is the study of identifying and choosing alternatives based on the values and preferences of the decision-maker. Making a decision implies that some alternatives are to be considered and that one chooses the alternative(s) that possibly best fits with the goals, objectives, desires and values of the problem*" (VIDAL ET AL 2010).

In order to choose one alternative, AHP will be applied. The method enables decision making for multi criteria decisions which don't have a single scale for measuring, but rather several scales. Furthermore it enables the rating of qualitative and quantitative criteria which makes it suitable for this application.

Level 1	**Functionality [100]**	**Reliability [100]**	**Usability [100]**	**Efficiency [100]**
Level 2	• Suitability • Accuracy • Interoperability • Compliance	• Maturity • Fault tolerance	• Understand-ability • Learnability • Operability	• Time • Resources

Table 5 Relevant Software Quality Attributes for AHP

The AHP builds on the goals and questions that have been identified in the GQM approach. The goals and subgoals of the AHP are equivalent to the GQM goals and questions, but AHP adds the component of the criteria's weights. The subcriteria of one superior criterion always add up to 100 points. The matrices will be created separately for the four criteria functionality, reliability, usability, and efficiency as well as their subcriteria. The four subcriteria of software quality will not be weighed among each other to add up to 100 percent. This is due to the basic idea of the thesis that software itself is a tool not a target and that the individual users have different priorities and requirements towards software. In case an element 1 of the matrix has further sub-criteria, a new matrix will be created with those. AHP consists of the three steps.

Figure 6 Steps of AHP process according to SAATY 1995

In the first step, hierarchy building is implemented. The criteria are ranked according to their importance for the superior hierarchy level. Several criteria can have the same importance and thus be on the same hierarchy level as can be seen in the following rank for the subcriteria of functionality.

Functionality	**Hierarchy**
Suitability	1
Accuracy	1
Interoperability	3
Compliance	2

Table 6 Hierarchies of functionality's subcriteria

In the second step pair-wise comparison matrices will be built. The Number shows the importance of a criterion in the row over a criterion in the column. The following rules, based on SAATY 1995 were applied for the construction of the matrices:

- For the measurement scale the five basic levels *equal* [1], *moderate* [3], *strong* [5], *very strong* [7] and *extreme* [9] importance are used.
- The pair-wise comparison matrix will not include intermediate values in order to get a more widespread result
- A comparison of a criterion with itself is always equally important [1]
- A reverse comparison of two elements is always the reciprocals

In the third step, the criteria's priorities will be calculated. Therefore the principal maximum eigenvalue and the corresponding eigenvector of the pairwise comparisons matrix need to be calculated. These calculations are implemented with the help of the online calculation program for AHP created by TAKAHAGI 2005 (http://www.isc.senshu-u.ac.jp/~thc0456/EAHP/EAHP_manu.html). The sum of the weights of a set of corresponding criteria will always be 1, respectively 100. Furthermore the Consistency Index (C.I.) of the matrices will be determined. In case it is greater than 0.1, the matrix will be reconsidered in order to guarantee the consistency of the matrices (TAKAHAGI 2005). In order to calculate a criterion's overall priority its weight is multiplied with the one of the superior criterion and divided by 100.

Functionality	Suitability	Accuracy	Interoperability	Compliance	**Priority**
Suitability	1	1	9	7	**44.0**
Accuracy	1	1	9	7	**44.0**
Interoperability	1/9	1/9	1	1/3	**4.0**
Compliance	1/7	1/7	3	1	**8.0**
					100

Consistency Index (C.I.) 0,03

Table 7 Pairwise Comparison Matrix for Functionality

Suitability [0.44]	Tool	Adaption	Variety	**Priority**	**Overall Priority**
Tool	1	7	7	**77.8**	**34.2**
Adaption	1/7	1	1	**11.1**	**4.9**
Variety	1/7	1	1	**11.1**	**4.9**
				100	**44**

Table 8 Pairwise Comparison Matrix for Suitability

The results of GQM and AHP will be established in an MS Excel Table for the purpose of checklist-base testing for the following GIS test analysis. The testing schema as well as the complete selection of matrices can be viewed in the Annex.

For the construction and metrics of the pairwise comparison matrices the following aspects were considered:

- *Maintainability* and *Portability* will not be considered as they are usually measured with static testing.
- *Suitability* of tools aims at checking whether there is an "out-of-the box" tool or if programming skills are required.
- *Compliance* will be defined as the capability to adhere to open standard data formats
- *Efficiency/Time/Steps* will be measured as the number of tools needed to perform the analysis
- The importance of *Efficiency/Time/Automation* can strongly depend on the company's focus; thus a medium level of importance was chosen
- The importance of *Usability/Learnability/Language* will strongly depend on the language skills of the user, thus a medium level of importance was chosen
- *Functionality/Accuracy* will be assumed when the resulting .shp file includes the required fields without containing NULL values or inconsistent data. Furthermore the

data's degree of detail in comparison to the other software will be included in the evaluation

- *Functionality:* When a tool does not get full points for suitability, it can still get full points for accuracy. However, if suitability is zero, accuracy will also be zero.

EVALUATION

All matrices have a Consistency Index smaller than 0.1. Consequently, the matrices were consistent in themselves. The AHP consists of up to 4 levels. While the three criteria efficiency, reliability, and usability had the same matrices, *functionality* is too specific to create a general schema. For this reason an individual matrix was created for each test analysis.

The evaluation schema showed two weaknesses. First, the same scheme was applied for the categories efficiency, reliability, and usability for spatial analysis but also basic applications like editing and georeferencing. While usability/operability is more important for basic applications, the category usability/learnability or usability/speed is more important for the utilization of complex tools. In the category *Usablity/Speed*, the time to perform the algorithm had the highest priority with 42.38 points. some analysis the calculation time is minor. Thus *operability* ranked too low compared to *speed* for editing and georeferencing.

The second crucial point concerns the category Reliability/ Maturity, more precisely the Question "Can the task/algorithm be performed completely in the first try?" This category had a rather high score with 42.15 out of 100 points. As the analysis could mostly not be implemented successfully on the first try, it may have been more insightful to rank the category troubleshooting higher as this part usually takes up the most time.

6 Parameters of ArcGIS and QGIS

In this section the parameters of ArcGIS and QGIS will be demonstrated. These include the software's development and distribution. Afterwards the topics costs and licenses, training and support, as well as the structure, and the tools of the programs will be presented.

6.1 Development and Distribution

#ArcGIS Development

The proprietary GIS software ArcGIS was developed by the company "Environmental Systems Research Institute, Inc." *esri*. Its headquarters are situated in Redlands California, USA and it has offices throughout the world. The company was founded in 1969 by Jack and Laura DANGERMOND as a research group working on land-use planning. Today they are the company's president and vice president. In the beginning, the company focused on the analysis of geographic information in order to consult land planners and resource managers in the field of environmental planning. In the middle of the 1970s *esri* was given the order by the County of San Diego, California to develop a polygon information overlay system. This was the company's first step to develop a geographic information system. In 1973 e*sri* created the first commercially developed statewide GIS software for Maryland. It was almost ten years later, in 1982 that the company started out in the software business with the proprietary GIS software called ARC/INFO (ESRI 2014). It was the first modern GIS software system which combined a computer display of geographic features with a database management tool [INFO] which could assign attributes to the features which were stored as arcs [ARC]. It also included a toolbox with command-driven user interface (MAGUIRE 2008: 25-31 & HOEN 1013). In 1986 the PC version of INFO 'PC ARC/INFO' which ran on IBM PC/AT under DOS 3.1 was released. In 1987, there were 1.500 ARC/INFO systems in use. The popularity grew with the release of ArcView 1, an affordable, user friendly desktop mapping tool in 1992 (ESRI 2014). In December 1999 ArcInfo 8 was released as a "*family of software products that formed a 'complete' GIS built on industry standard [sic!] that provides powerful, yet easy-to-use capabilities right out of the box*" (MAGUIRE 2008: 26). Today ESRI has around 3.000 employees worldwide. It has 10 regional offices in the US and over 80 distributers throughout the world (SCOTT & JANIKAS 2010: 27). ArcGIS is available as ArcGIS Online, ArcGIS for Desktop, ArcGIS for Server and Portal for ArcGIS. ArcGIS for Desktop is a GIS program which can perform spatial analysis on vector and raster data, edit and geocode data, and produce high-quality maps. It includes the program ArcGIS Online which represents a mapping platform for the creation of interactive web maps and apps. The current release from April 15th 2014 is ArcGIS for Desktop 10.2.2. It can upgrade an existing installation of the same ArcGIS 10.1 or 10.2 software. ArcGIS products have a limited life cycle. For the current version 10.2.2 extended support will run out August 1st 2017 and the version will fully retire August 1st 2019 (ESRI 2014).

ArcGIS for Desktop has been certified for Windows operating systems (Windows XP, Vista, 7, 8). The software cannot be used on Mac, Linux, or BSD operating systems. ArcGIS for Desktop can be used on apple computers which run Windows with the help of VMWare, BootCamp, or Parallels (ESRI 2014). ArcGIS for Desktop is available for download in 10 languages: Arabic, Chinese, Japanese, German, French, English, Italian, Spanish, Portuguese, and Russian. ArcGIS Resource Center is translated to 7 languages.

Although *Ersi*'s software is proprietary, the development process includes elements of open source development. *Esri* provides a system for reporting software errors and has established an *Esri* User Experience Improvement Program. When the software closes down unexpectedly with the message "*ArcGIS has encountered a serious application error and is unable to continue*." an error report file (.dmp) is automatically generated on the hard drive and can be sent via a Send Error Report button. The User Experience Improvement Program aims at improving the interaction and navigation within the software. When users choose to participate in the program, by activating it during the installation process, data about the use of tools, hardware and operating system information is collected (GLENNON 2012).

#QGIS Development

Comparatively to ArcGIS, QGIS is an open source GIS. It exists for the operating systems Windows, Mac OS X, Linux, BSD and Android (beta). QGIS software is developed by using the programming language C++ and the modules of the open source project *Qt Project* (QGIS 2014) which is a cross-platform application and user interface framework (QT PROJECT HOSTING 2014). The "Q" in QGIS relates to the one from *Qt Project*. Before the 2.0 release in September 10th 2013, the program was known as *Quantum GIS* as well as *QGIS* and is exclusively called *QGIS* since then. QGIS is available in 42 languages. QGIS consists of four elements, QGIS Desktop, QGIS Browser/Mobile, QGIS Web Client and QGIS Server. QGIS Desktop is the equivalent to ArcGIS for Desktop as it provides GIS functions for data creation, viewing, editing, and analysis. QGIS Server represents a standard-compliant WMS 1.3 server that can be configured with project files from QGIS Desktop (QGIS 2014).

As QGIS is open source, the development process is very different to that of ArcGIS. QGIS project was started in 2002 by the Alaskan programmer Gary SHERMAN who was looking for a fast geographic data viewer which runs on Linux and supports several data formats. As a result of his unsuccessful search he decided to start his own GIS project. In June 2002 QGIS was officially registered as a project of the Open Source Geospatial Foundation (OSGeo), a not-for-profit organization with the aim "*to support the collaborative development of open source geospatial software, and promote its widespread use*" (OSGeo 2014). The second developer in October 2002 was Marco HUGENTOBLER from the University of Zurich. The software is being written by a core development team and a worldwide community. There are more than 50 developers of which 30 are regularly active. The major development is conducted in Middle Europe. QGIS has for instance user groups in Switzerland, the UK, and Austria (NEUMANN 2014: 15-16). The chart on the development of QGIS committers by the project's founder SHERMAN shows an increase in developers that peaks in 2008. Since then the number of new committers is shrinking which indicates that the core development team is rather stable.

QGIS has a plugin architecture that enables the adding of new features. Plugins can be written by developers in Python or C++ with the help of the integrated Plugin Builder in QGIS, or through the creation of their own fork on QGIS repository at *Github* (QGIS FOUNDATION 2014), a website for code review and management for open source and private projects (GITHUB INC. 2014). QGIS foundation will approve plugins so that quality control is guaranteed. On the official QGIS plugins web portal [http://plugins.qgis.org] developers can find a list of all stable and experimental QGIS plugins as well as a manual for creating their own plugins.

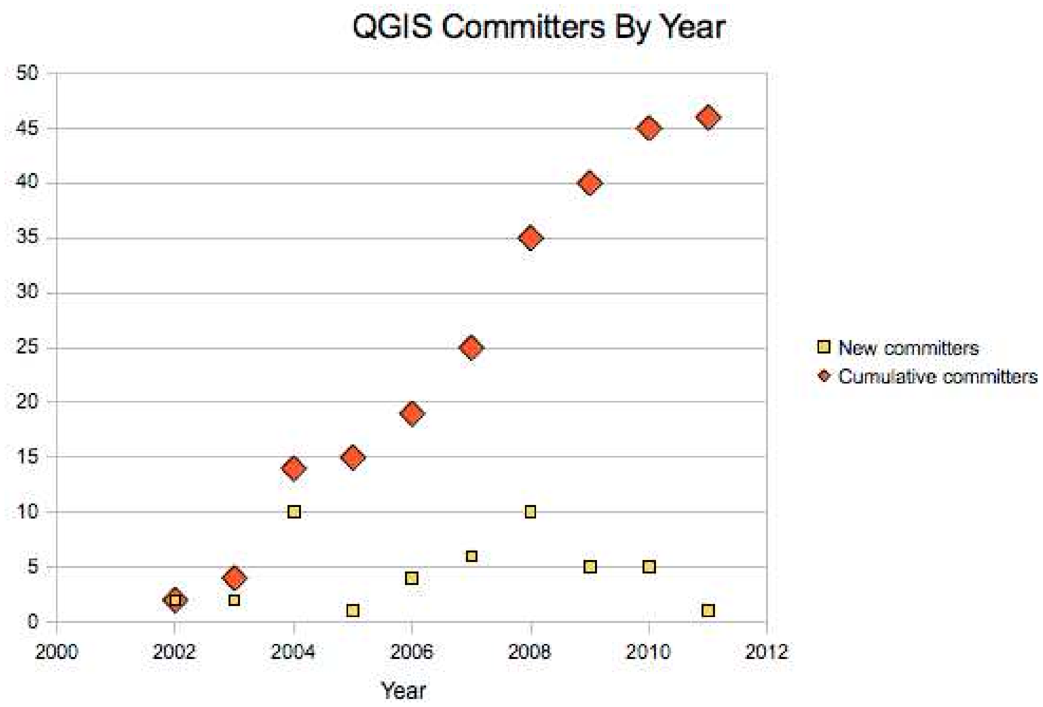


Figure 7 QGIS Committers 2002-2011, Source: SHERMAN 2011a

Although the software is available free of charge, there are several elements that finance the development teams' work and infrastructure. These are for instance development contracts and paid software integration for companies and state institutions. Other sources of income are service, support, maintenance and courses as well as cloud services. Moreover, QGIS user groups can collect membership fees (NEUMANN 2014). Another feature is sponsoring and donations from government agencies, companies and individuals. Currently QGIS project has 8 sponsors [effective: Oct 2014] of which the most important one is Asia Air Survey (QGIS 2014). In accordance with the idea of an open source project users are encouraged to join and support the community. These can be done in several ways. First, users can actually participate in writing tools and plugins for the software. Furthermore the project can be supported by translation work or participating in support channels. Moreover users can ask for the programming of new features and report bugs with QGIS bug tracker (http://hub.qgis.org/projects/quantum-gis/issues) (QGIS FOUNDATION 2014). The organization also maintains a WIKI website (http://hub.qgis.org/projects/quantum-gis/wiki) on which users are being informed about issues concerning the development of QGIS as well as release plans, links to download sites or message translation-hints.

The first version for Windows version 0.5 was released in October 2004. The current version which is used in this thesis is QGIS 2.6. It was released on November 1st 2014 and carries the name "*Brighton*". In 2014, the QGIS development team decided to have a new release every fourth months. The next developer version (2.7) will be available on January 23rd 2015 and the next stable version (2.8) on February 20th 2015. The development plan foresees a three month development phase and a one month phase for bug fixing, translation, and testing.

#Distribution of ArcGIS and QGIS

ArcGIS, "*leader in the GIS software industry*" (PEARSON EDUCTION 2014) has the bigger market share among the two GIS software. ArcGIS software has more than one million users worldwide and is installed at over 5.000 universities (SCOTT & JANIKAS 2010: 27). It is popular for government and commercial agencies. As QGIS is open source software and doesn't have registered licenses, the number of active user is hard to predict. The founder SHERMAN conducted a study in 2011 in which he used the log files from the QGIS contributed repository and geocoded the IP addresses of each entry that retrieved the plugin list from the QGIS server. In this way he could estimate the number of active QGIS users to a minimum of 100.000 users (SHERMAN 2011). Consequently QGIS has a smaller market share than ArcGIS. However, its popularity has been growing relatively fast in the last decade. It is especially popular in academia and open source software user circles (DEMPSY 2012). Nevertheless, there are also examples for QGIS implementations in public institutions. Already in 2006 the Swiss Canton of Solothurn decided to use QGIS instead of *Esri* products (DÜSTER 2009). The state administration of the region *Land Vorarlberg*, Austria can be named as another example of a public institution that exchanged their Desktop GIS version with QGIS (LAND VORARLBERG 2014).

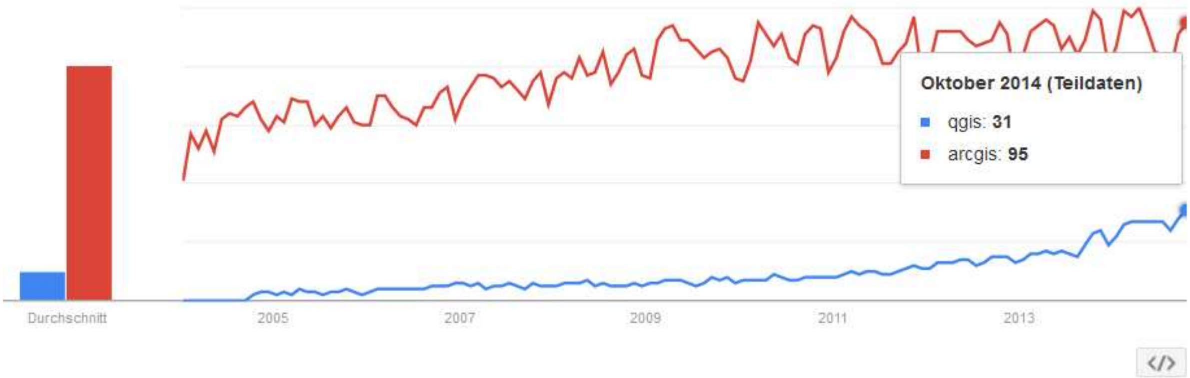


Figure 8 Search Requests "ArcGIS" and "QGIS" 2004- 2014, Source: Google Trends 2014

The growing interest in QGIS is reflected within the internet search engine *Google*. The chart shows the development of search requests between 2004 and 2014 as normalized values. Thus, the score of search requests on *Google Trends* showed that the ratio of searches "QGIS" and "ArcGIS" changed from approximately 2/69 in October 2004 to 31/96 in October 2014. While the interest for ArcGIS has been fluctuating around the same value since 2011 with the highest peak April 2014, QGIS search request have been continuously growing since then.When analyzing the change of QGIS separately, it is visible that the interest in QGIS started rising in 2011 where it still scored 24/100. Since Jan 2013 the searches for QGIS doubled from 46/100 to 100/100 search requests.

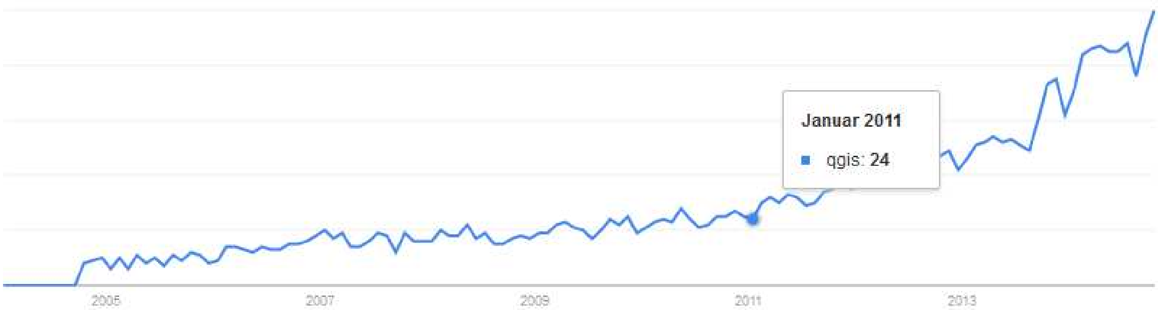


Figure 9 Search Requests for "QGIS" 2004-2014, Source: Google Trends 2014

Figure 10 Normalized Distribution of Search Requests "ArcGIS" [left] and "QGIS" [right], Source: Google Trends 2014

The analysis of the software's regional distribution shows hot spots for QGIS search requests in Italy, France, Portugal, South Africa, Ecuador, and Switzerland. ArcGIS has the high scores in Ethiopia, Bolivia, China, Mongolia, Ecuador, and Nicaragua. The highest interest in QGIS in Europe can also be seen in the following example: While the USA scores 26 for ArcGIS and 18 for QGIS as Austria scores only 17 for ArcGIS but 56 for QGIS.

6.2 Costs and Licenses

#ArcGIS Costs

ArcGIS is a proprietary software product. There are different versions with varying prices available. Concerning ArcGIS for Desktop, there are three versions with different prices and increasing functionalities. These are *ArcGIS for Desktop Basic*, *ArcGIS for Desktop Standard* and *ArcGIS for Desktop Advanced*. They were called *ArcView*, *ArcMap*, and *ArcInfo* before the 10.0 release. *ArcGIS for Desktop Basic* is suitable for building maps and exploring geographic information, *ArcGIS for Desktop Standard* additionally holds tools for multiuser editing and advanced data management and *ArcGIS for Desktop Advanced* enables advanced analysis and data conversion. In addition to the main software, twelve so called *extensions* in the categories of Analysis, Productivity, and Solution based can be purchased. The extensions used in this thesis's GIS analyses are Network Analyst, Spatial Analyst, and 3D analyst (ESRI 2014). Altogether, a version of ArcGIS will cost around 2.500€ - 25.000€ per license, plus additional yearly costs for optional support which can be up to 4.000€, depending on the version and the status of the company or organization. However, *Esri* provides a 60 days trial version of ArcGIS Desktop Advanced for private users as well as companies. Additionally students have the possibility to receive a one year ArcGIS for Desktop Student Trial (ESRI 2014).

In contrast to ArcGIS, QGIS is an OS project which implies that the software is available free of charge. This is also true for updating old versions and the installation of plugins. The software can be downloaded without registration on the official QGIS project website or the OS community website *Sourceforge* (http://sourceforge.net) on which QGIS is registered since

December 2nd 2011. It is the largest OS directory where IT professionals develop, download, review, and publish open source software (Sourceforge 2014).

Concerning the source code, ESRI protects its source code in the license agreement as it is a proprietary software company. "*Esri Software source code is unpublished, and all rights to Products are reserved by Esri and its licensors*" (ESRI 2012: 6). Thus the source code is protected and may not be used to build other applications on it. "*License may not provide third parties with direct access to Esri Software so that the third parties may use the Software directly, develop their own GIS applications, or create their own solutions in conjunction with the Software*" (ESRI 2012: 2). With the purchase of the software, the user does not own it. "*Products are licensed, not sold. Esri and its licensors own Products and all copies, which are protected by United States and applicable international laws, treaties, and conventions regarding intellectual property and proprietary rights including trade secrets*" (ESRI 2012: 2). *Esri* differentiates between single use licenses which are locked to a single computer and concurrent use licenses which enable several computers to use the software concurrently with the help of a central license manager (ESRI 2014).

QGIS is licensed under the GNU General Public License which was created by the FSF for the project GNU operating systems in 1989 (RENNERT 2000: 50). In specific it holds the Creative Commons Attribution-ShareAlike 3.0 licence *CC BY-SA* (QGIS 2014). This means, that users are allowed to share and adapt the software. More precisely the term "share" means to "*copy and redistribute the material in any medium or format*" (CREATIVE COMMONS 2014) and "adapt" means to "*remix, transform, and build upon the material for any purpose, even commercially*" (ebenda 2014). In order to have these rights it is necessary to adhere to the license terms. These ask for "Attribution" and "ShareAlike". Attribution means, that the user has to give "appropriate credit". Moreover he or she has to set a link to the license and mark potential adaptions. By doing so the user must take into account, that he may not do it in any way "*that suggests the licensor endorses you or your use*" (ebenda 2014). The task "ShareAlike" indicates, that the user has to distribute his product under the same license as the QGIS license in case a new product is created by remixing, transforming, or building upon the QGIS source code. In addition it is not possible to use legal terms or technological measures which legally restrict others from doing anything the license permits (ebenda 2014).

6.3 Training and Support

#Trainings

"*Esri offers hundreds of training options on GIS, ArcGIS technology, and related topics*" (ESRI 2014). These training options include free and chargeable trainings, individual virtual campus training and instructor led trainings. In order to learn ArcGIS for desktop there are 169 options available. *Esri* provides a free Resource Centre which is available in seven languages. It includes the ArcGIS help (http://resources.arcgis.com/en/help/main/10.2/) which is structured by ArcGIS versions and products. Trainings date back to ArcGIS version 9.1. *Esri*'s Resource Centre also hosts a blog (http://blogs.esri.com/esri/arcgis/) and forums (http://forums.arcgis.com/) which are systematically organized by different categories. Furthermore there is a section with videos available on http://video.arcgis.com/.

Apart from the Ressource Centre, *Esri* offers a variety of free tutorials and chargeable classes. On the official website one will find 92 free web courses and training seminars [effective 16.08.2014]. In order to have access to them, the prospect needs to have an *Esri* global account, which is free of charge but requires the exposure of personal data. In addition there are free live training seminars which can be streamed.

Furthermore, there are chargeable web courses for ArcGIS which cost 32USD [24Euro] for a 2-4 hour class. Besides the web classes, ArcGIS can be learned by taking instructor led classes. Costs vary between 1010USD [754 Euro] for 16 hours and 2.525USD [1884 Euro] for 40 hours. Teachers of *Esri* classes hold the international CompTIA CTT+ certification. Moreover the possibility exists to hire an *Esri* instructor for a specific training inside a company. Above there is training for organizations including course recommendations creation of specific project related training, and long term development plans for employee's training (ESRI 2014).

For ArcGIS it is possible to receive ESRI Technical Certificates by taking exams. These can be obtained for a fee 225 USD [~160Euro] via *Esri*'s partner *Person Education* in approximately 5.000 test centres worldwide. Vienna for instance hosts five testing institutions (CF. PERSON EDUCATION 2014). There is also a large number of books available. A search request on online warehouse *Amazon* from Oct 2014 revealed more than 30 books.

Likewise there are trainings for QGIS available. The QGIS Website provides several guides and tutorials to work with the software. Similar to ArcGIS Resource Centre, QGIS has a User Guide which is a structured documentation about the QGIS functionalities available as online manual or .pdf print version. It is updated with every update of QGIS but is also available for older versions. Additionally there is a training manual with different courses available and for GIS beginners a *Gentle introduction to GIS*.

A possibility to solve concrete QGIS issues is the "Qgis-users mailing list" were specific questions concerning the installation and use of the software can be asked. In this way user questions reach a broad audience and answers can benefit several users. The QGIS development team also maintains a presence on the Internet Relay Chat IRC were users can exchange ideas. It can be joined by users via a specific QGIS channel on the website *freenode.net*. All discussions are being logged and can be viewed on the QGIS homepage (http://qgis.org/irclogs). Furthermore the QGIS community maintains a blog (http://planet.qgis.org/planet/) which contains articles for users and developers. Concerning literature, there is only one book about QGIS on the market so far which is "*Learning QGIS 2.0: Use QGIS to create great maps and perform all the geoprocessing tasks you need*" by Anita Grasser published in 2013.

#Commercial Support

In terms of commercial support, "*Esri has a well-established knowledge base, peer support forum, and technical support system for its ArcGIS product*" (MORAIS 2012). Support is available for the versions 9.x and higher. ESRI's support structure for the US is divided into standard, and premium types of support. Furthermore there is the Customer Support which is in charge of addressing issues concerning licensing and registration of ArcGIS software. Countries outside the US have authorized international distributors that are listed on ESRI's website http://support.esri.com/en (ESRI 2014).

Comparable to ArcGIS, there are several companies that focused on commercial support for QGIS software. In total there are 30 companies, twelve of them are so called "core supporters"

[Effective: November 18th 2014] for which QGIS foundation takes the full responsibility for their “*accuracy, reliability or completeness of the provided information*” (QGIS 2014). Three of the core supporters *Opengis.ch* and *sourcepole.com* based in Switzerland, and *faunalia.it,* based in Italy and Portugal operate worldwide (QGIS 2014).

7 Software Structure and Functionality

After the parameters of ArcGIS and QGIS have been presented, this chapter will discuss the programs' structures and functionality. The chapter is also the basis for the further one in which the test analyses will be implemented.

7.1 Installation and Graphic User Interface

Installation

	ArcGIS 10.2.2	QGIS 2.4
Required Memory	1.89 GB	1.2GB
How long does the installation process take?	15:01 min	22:15 min
Authorization required	Yes	No

Table 9 Benchmarks for Installation

On Esri's website information on the different ArcGIS for Desktop versions and their contents can be found. A license itself can only be purchased by contacting the local ESRI distributer. In case of the Student license, the authorization code and an ArcGIS version were purchased at the university. As ArcGIS is a proprietary software, apart from the installation process an authorization is required. For the authorization it is necessary to create a user account on Esri's homepage https://accounts.esri.com/signup. After registering with the full name and a valid e-mail address the user will receive an email from Esri with a link to activate his or her account. To do so the data *Full name, Organization, Address,* and *Phone Number* have to be revealed and a license agreement needs to be accepted. In the next step the user can either install an *ArcGIS for Desktop* version via an external disk or download the version from the homepage after the purchased authorization number was entered. In this test the software was downloaded as it enables the installation of the latest version ArcGIS 10.2.2 for Desktop. Apart from the GIS program, the Service Pack *Microsoft .NET Framework* needs to be downloaded and installed including updates. Microsoft will further recommend installing the latest Internet Explorer and Microsoft Windows Malicious Software Removal Tool. Subsequently, ArcGIS for Desktop software can be installed. The installation with an installation wizard takes 15:01 min. The installation package includes Python 2.7.5, Numerical Python 1.7.1 and Matplotin 1.3.0. After the software's installation the product can to be authorized via the Internet whereby the identical authorization information needs to be added that had been used for the Esri User Account. Additional information on the user's organization, industry and person is required.

QGIS software can be downloaded from the official project website http://qgis.org/. As QGIS is an open source software, the user can decide between installing the latest stable release version and the developer version (master) for the desired operating system. There are two options for the QGIS installation available. The *standalone installer* is one large download (258MB) in which a QGIS release as well as GRASS GIS and SAGA GIS are included. The second option which was used in this case is *OSGeo4W installer*. It is a small installation tool (878KB) which enables the download and installation of QGIS but also other OSGeo tools and facilitates future updating processes of QGIS and its dependencies (GRASER 2013). Apart from QGIS, GDAL, and GRASS GIS were installed with *OSGeo4W installer*.

The installation time was 22:15 min in QGIS and 15:01 min in ArcGIS. Nevertheless the entire installation process took double the time for ArcGIS due to the sophisticated registration process and the installation of *Microsoft.NET Framework*. Moreover there was no installation manual required for QGIS as the process is rather self explanatory. For ArcGIS the installation manual was needed though. QGIS was later updated from QGIS 2.4 to QGIS 2.6 with *OSGeo4W installer*. In that way the setting of QGIS 2.4 like toolbars and plugins were automatically applied for the new QGIS 2.6 version. All projects that were saved with QGIS 2.4 could be used in the new version without difficulties.

#Graphic User Interface

ArcGIS and QGIS have similar Graphic User Interfaces (GUI). They consists of five elements, namely the main menu bar on top, tool bars, the map legend or table of contents, the central map view, and the status bar at the bottom. As the GIS programs offer a huge set of functionality the required toolbars and windows can be added, scaled and arranged according to the specific task. According to the developer team the QGIS "*…GUI convention styles are intended to mimic the appearance of the GUI*" (QGIS Development Team 2013/2014: 3). The same can be seen in ArcGIS. Both programs are similar in terms of structure and use the same color scheme with blue and grey as dominant color. The color grey generally has the effect to appeal elegant and slick to a user.

The two programs use direct manipulation and menu selection. Symbols facilitate the access to the functions. Moreover, color schemes, shortcuts and commands icon can be individually adapted. The map can be zoomed with the Mouse Wheel and panned with arrow keys and space bar.

When installing the software, QGIS applies the operating system's default language. However, the language can easily be changed to one of 42 languages in the menu settings. After selecting a different language, only a restart of the program will be necessary to work with the GUI of the selected language. In ArcGIS the user will order the software with the preferred language. A change of language at a later moment is not possible.

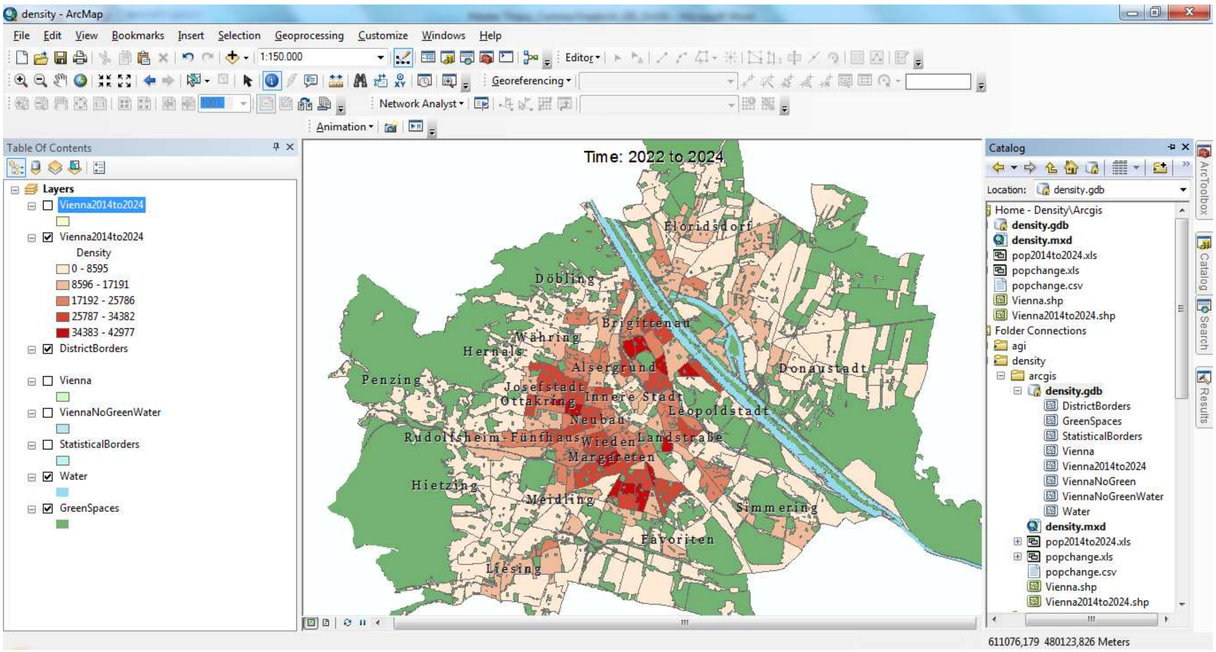


Figure 11 ArcGIS GUI

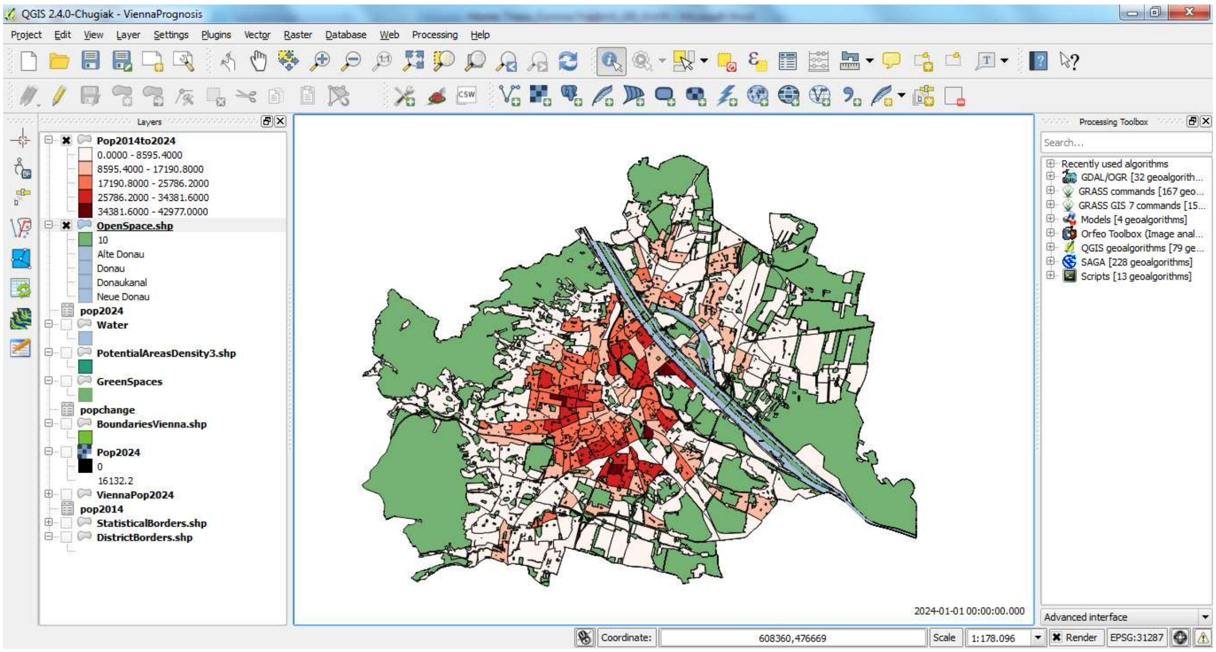


Figure 12 QGIS GUI

7.2 Data Formats and Data Management

ArcGIS and QGIS can both handle diverse sets of vector, raster, and tabular data as well as web services.

#Raster Data

ArcGIS for Desktop supports around 70 ***raster data formats***. The full list of supported raster data formats can be viewed in Esri's Resource Center http://resources.arcgis.com/en/help/main/10.2/index.html#/Supported_raster_dataset_file_formats/009t0000000q000000/.QGIS used the GDAL/ORG library to read and write raster and vector formats. GDAL supports 133 raster formats [Effective: 22.08.2014]. The complete list can be viewed on the website http://www.gdal.org/formats_list.html. Popular raster formats which are supported by both programs are for instance IMG, TIF, TFW, JPEG, JPEG 2000, JPGW, GIF, PNG or BMP. However there also differences. The proprietary ArcSDE Raster is read only in QIGS, the Arc/Info ASCII Grid is fully supported. On the other hand, QGIS works with GDAL Virtual and SAGA GIS Binary format which are read only in ArcGIS or GRASS Raster [read only], GRASS ASCII Grid and R Object Data Store which are not supported in ArcGIS.

#Vector Data

ArcGIS and QGIS both support popular ***vector data formats*** like DXF, SVG, GML, GPX or KML. Nevertheless, the most frequently used vector format is ArcGIS shapefile [.shp] which represent a nontopological format for storing the geometric location and attribute information of geographic features. QGIS also uses the ESRI shapefile as a standard vector file format. However, the performance can be improved by creating a spatial index [.qix extension]. When saving a shapefile, QGIS creates two projection files. The first one [.prj] contains limited projection parameters and is compatible with ArcGIS and the second one [.qpj] holds the full information for the CRS. Additionally GDAL supports 79 vector formats [Effective: 22.08.2014]. The complete list can be viewed on gdal's website http://www.gdal.org/ogr_formats.html (GDAL 2014).

#Tabular Data

Concerning Tabular Data in QGIS CSV/TXT, WKT and MS Office Open XML spreadsheet are fully supported. MS Excel format can only be read. In ArcGIS CSV/TXT files are read only. Data from MS Excel spreadsheets can be read directly in ArcGIS or through OLE DB, Microsoft Access only through OLE DB (ESRI 2014).

#3D Data

ArcGIS can handle 3D data with the help of the Extension 3D Analyst. COLLADA, lidar, SketchUp, OpenFlight data, and others can be used to create and analyze surface data in raster, terrain, triangulated irregular network (TIN), and LAS dataset. In QGIS 3D data is not supported. So far there is only the plugin *Qgis2threejs* exists. It combines terrain data, a map image and optional vector data in an html file which can be viewed in 3D in a WebGL supported web browser.

#Web Services

In ArcGIS solely WMS and WMTS, WCS can be added via the Add Data Dialog box or the Catalog Window. In order to work with WFS contents in ArcGIS for Desktop the extension *Data Interoperability* is needed, and an Interoperability Connection to the WFS service has to be added. QGIS supports the access to, and writing of several web services, namely WMS, WMTS, WFS, WCS, WPS, and CSW. Adding Web Services in QGIS works the same way as adding a regular vector layer by clicking the adequate symbol and adding the web-address. WMS is handled like a raster layer and WFS like vector layers. WPS and CSW can be handled with the help of plugins. Furthermore there is a plugin for OpenLayers which enables to work with Google Maps, Bing Maps, and OpenStreetMap. ArcGIS provides an Editor for OpenStreetMap Add-on.

The Map Services are read only. Sharing Online Data in both cases requires ArcGIS for Server respectively QGIS Server which will not be discussed in this thesis.

Web Services [read only]	ArcGIS	QGIS
WMS (Web Map Service)	yes	yes
WMTS (Web Map Tile Service)	yes	yes
WFS (Web Feature Service)	yes	yes
WMC (Web Map Context)	yes [add-on]	yes
WCS (Web Coverage Service)	no	yes
WPS (Web Processing Service)	no	yes [plugin]
CSW (Catalogue Service for Web)	no	yes [plugin]

Table 10 Supported Web Services in ArcGIS and QGIS

#Data Storage

In ArcGIS shapefiles are usually stored in *feature classes*. A *feature class* represents a repository of geographic features with the similar geometry type and the same attribute fields for a common area. Feature classes with spatial or thematic similarities are often organized in a *feature dataset* with a shared coordinate system. ArcGIS requires that feature classes are organized in feature datasets to be able to perform certain tasks like building networks, terrains or using topology. Feature Datasets are generally stored in *geodatabases*.

The ***geodatabase*** is the core information model in ArcGIS. The geodatabase represents a physical store of geographic datasets of different types of dataset tables as well as system tables which determine the integrity and behavior of the geographic information. The datasets can be feature classes, raster datasets, and tables. The geographic datasets are held either on disk or a multiuser relational data base management system (DBMS). There are three types of ArcGIS geodatabases, Personal-, File-, and ArcSDE. These are proprietary ESRI formats. Personal databases have a limit of 2GB and all data is stored in MS Access data file. File geodatabases can be up to 1TB and are stored as a directory in a file system. ArcSDE database represents a relational multi-user database with unlimited size. ArcGIS supports IBM DB2, IBM Informix, Oracle, PostgreSQL, and MS SQL Server DBMS (ESRI 2014). A precondition for the connection to a DBMS is an installed database client. It needs to be compatible with the release of the DBMS to which the user wants to connect. The access to a database is established with a connection from the Database Connections node in the *ArcCatalog* window (ArcGIS Resources 2014).

Compared to ArcGIS geodatabase, QGIS primarily works with the OS ***SpatiaLite*** **Layer**. *SpatiaLite* is the spatial extension for *SQLite*, the most widely developed SQL database engine. It represents a software library that implements "*a self-contained, serverless, zero-configuration, transactional SQL database engine*" (SQLite CONSORTIUM 2014). Thus *SpatiaLite* databases, do not need a server installation but can be copied and exchanged in the same manner as computer files (GRASER 2013). Additionally, SQLite is compatible with other open source products like for instance GDAL library. QGIS further supports PostgreSQL/PostGIS (OS), MS SQL Spatial, SQL Anywhere, and Oracle Spatial databases. They are added in the same way as layers via the *Add SpatiaLite Layer* symbol or the Browser. Additionally, there is an integrated database manager available (QGIS DEVELOPMENT TEAM 2014).

	ArcGIS	**QGIS**
Oracle Spatial	yes	yes
SQLite/SpatiaLite	yes	yes
PostgreSQL/PostGIS	yes	yes
MS SQL Spatial	yes	yes
SQL Anywhere	no	yes
IBM DB2	yes	no
IBM Informix	yes	no

Figure 13 Supported DBMS of ArcGIS and QGIS

Data Management Structure

In ArcGIS data can be managed in the external program *ArcCatalog* which is part of the ArcGIS for Desktop package. It is a program to manage and analyze data. *ArcCatalog* has folder connections for accessing the computer's hard disks and it shows the data's organization. Up to ArcGIS for Desktop Version 9.x there was no connection between *ArcCatalog* and *ArcMap*. Since then *ArcCatalog* can also be added as a window and be accessed from within *ArcMap* (ESRI 2010). The equivalent for data management in QGIS is a *Browser* which can also be opened separately or through the *Browser window* that connects to the computer's hard disks and shows the data's organization.

Table 11 Data Import Toolbars in ArcGIS [top] and QGIS [bottom]

In ArcGIS all data formats can be imported with the help of the *add data* symbol while in QGIS datasets are imported according to their data types via corresponding symbols. Moreover datasets can be added by drag and drop from *ArcCatalog* (ArcGIS) or *Browser* (QGIS) to the map view.

In ArcGIS *map documents* are saved as internal .mxd-file, in QGIS *projects* as .qgs file. These documents do not contain the data used in the projects but they store the data connections and project settings. Data can be saved in geodatabases (ArcGIS) or SpatiaLite Layers (QGIS) and geoprocessing workflows as models and scripts. ArcGIS can further create Geoprocessing packages [.gpk].

7.3 Raster and Vector Analysis Tools

ArcGIS and QGIS provide a wide range of tools to geocode, edit, manage, and analyze raster and vector data. The structure of the programs is very different though.

ArcGIS Spatial Analysis Toolbox

ArcGIS has a large toolbox with several hundred algorithms for vector and raster analysis. Basic Tools are part of the core software while additional tools can be purchased as *extensions* according to the user's needs. Once they are installed in ArcGIS they can be activated through the integrated extension manager. Extensions that will be used in this thesis are *Spatial Analyst*, *Network Analyst,* and *3D Analyst*. Overall there are twelve extensions in the fields of Analysis, Productivity, and Solution Based.

Analysis (according to ESRI 2014)

- ArcGIS Extensions: Specialized GIS tools for
- Enhanced Productivity and Advanced Analysis
- ArcGIS Spatial Analyst: Advanced spatial analysis
- ArcGIS 3D Analyst: Management and analysis of data in 3D
- ArcGIS Geostatistical Analyst: Advanced Statistical Tools
- ArcGIS Network Analyst: Solving Sophisticated Vehicle Routing, Closest Facility, Service Area, and Location-Allocation Problems
- ArcGIS Schematics: Representing and Understanding Networks for shorter Decision Cycles
- ArcGIS Tracking Analyst: Visualization and Analysis of Assets and Resources in Time and Space

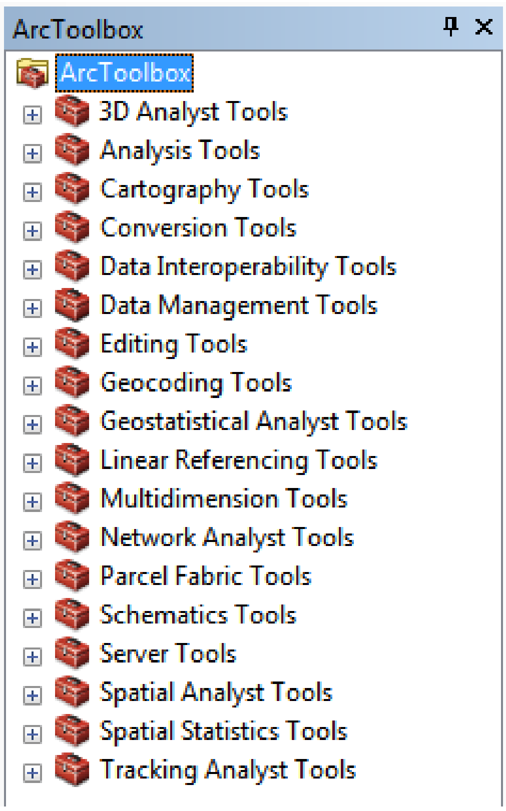


Figure 14 ArcGIS Toolbox, Source: Esri 2014

Productivity

- *ArcGIS Publisher*: Sharing maps and data with multiple users

- *ArcGIS Data Interoperability*: Elimination of format barriers to data use and distribution
- *ArcGIS Data Reviewer*: Automation and improved management of data quality control
- *ArcGIS Workflow Manager*: Improved management of GIS tasks and resources

Solution Based

- *Esri Production Mapping*: Standardization and optimization of GIS data and cartographic production (ESRI 2014)

Add-Ons

Furthermore, *Esri* provides no cost Add-Ons for ArcGIS for Desktop licenses. These are an Editor for OpenStreetMap, a Districting Tool, an S-57 Viewer, Geoportal Add-ons, U.S. National Grid Tools, a WMC Client, and an Add-On to view and write NITF data within ArcGIS. There is no internal add-on manager within ArcGIS for Desktop but Add-ons are downloaded from Esri's homepage. It is not necessary to sign in to Esri's global account; however a license agreement needs to be accepted. After downloading the correct version, unzipping and installing the add-on, it will show up as ArcGIS toolbox. In order to use an add-on it has to be activated first by checking it in the *Extensions*.

#QGIS Plugins

QGIS software has a plugin architecture which enables the user to add new features and functions to the main program free of charge. On November 18th, 2014 there were 235 stable, 89 experimental and three deprecated plugins available. There is a set of so called core plugins which are already pre installed. Plugins can be downloaded and installed with the help of an integrated plugin manager which is accessible through the main menu. The user can select from a list of all available plugins, filter by category, or search with a search window. The installation only requires the selection of the required plugin and a click on an installation button. No registration or confirmation of a license agreement is needed. Once installed, the new features will automatically be added as a button to the tool bar. Examples for core plugins which will also be used in this thesis are *fTools* for vector analysis and management tools, *GdalTools* for raster analysis and management tools or *Processing* for raster and vector analysis tools from third party algorithms.

#QGIS *Processing* Analysis Framework

Compared to ArcGIS, QGIS itself has a limited amount of internal geoalgorithms. The 85 algorithms are divided into Database, Raster, Table, and Vector tools. QGIS only has limited internal raster manipulation tools for Raster Style and Statistics. Vector manipulation algorithms include a broader range of tools in the fields analysis, creation, general, geometry, overlay, selection, and table tools.

However, QGIS code is split into several libraries, so that third party applications can link to it and use it. The *Processing* Plugin provides a framework for geospatial analysis to call native and third party algorithms from QGIS, such as GDAL, SAGA, GRASS, R, Orfeo or OSSIM (QGIS 2014 & Neumann 2014: 2).

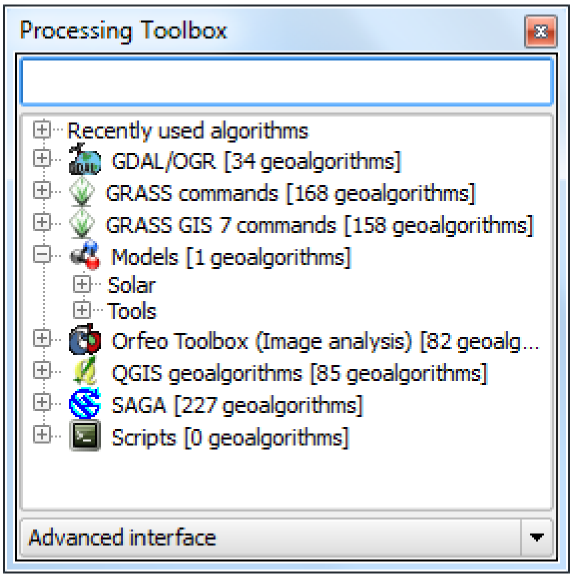


Figure 15 QGIS Processing Toolbox, Source: QGIS 2.6

GRASS GIS Geographic Resources Analysis Support System

SAGA GIS System for Automated Geoscientific Analyses

Orfeo Toolbox OTB for photogrammetry

OSSIM for image processing

R software environment for statistical computing and graphics

The open source GIS **G**eographic **R**esources **A**nalysis **S**upport **S**ystem ***GRASS GIS*** has been under development since 1982, first by the U.S. Army – Construction Engineering Research Laboratory in Illinois, USA and then after 1997 by academia worldwide. The software holds more than 400 modules but has limited possibilities for interactive viewing. With the help of the *GRASS* plugin QGIS can be extended as a viewer for GRASS vectors and rasters. Using the GRASS toolbox, spatial analysis which is conducted in GRASS itself can be started from the QGIS GUI. GRASS commands in QGIS include 168 tools for Imagery, Raster, Vector, Visualization, and Miscellaneous. Around 100 of them are raster manipulation tools (GRASS Development Team 2014 & QGIS Development Team 2014).

The FOSS GIS **S**ystem for **A**utomated **G**eoscientific **A**nalyses ***SAGA*** began development in 2001 at the Department of Physical Geography, University Göttingen. Since 2007 SAGA development has been conducted by the Department of Physical Geography, Hamburg. The 227 modules that can be used in QGIS have a focus on Geostatistics, Grids, Imagery, Kriging, Shapes, Simulation, Tables, and Terrain Analysis (SAGA USER GROUP ASSOCIATION 2014).

Orfeo is an open source library for image processing algorithms. It was developed by the French Center for Spatial Studies *CNES* and is based on the medical image processing library Insight Segmentation and Registration Toolkit *ITK*. The Orfeo Toolbox ***OTB*** provides functionalities for remote sensing image processing as well as for high spatial resolution images (CNES 2013). It provides 82 tools for Image analysis in QGIS in the categories Calibration, Feature Extraction, Geometry, Image Filtering, Image Manipulation, Learning, Segmentation, Stereo,Vector Data Manipulation, and Miscellaneous.

The free software environment for statistical computing and graphics ***R*** began development in 1992 at University Auckland. It is a computer language as well as a run-time environment including graphics, a debugger, access to system functions, and it can run programs in form of script files (R FOUNDATION 2014).

OSSIM is an open source software being developed since 1996, for processing imagery, maps, terrain, and vector data. Features include precision terrain correction and orthorectification, advanced mosaicking, compositing and fusion, histogram matching, rigorous sensor modeling, or parameter based image chains. OSSIM is one of the founding projects of the OS Geospatial Foundation that started out in 2005 (OSSIM 2014).

7.4 Scripting and Automation

ArcGIS and QGIS both hold options to automate process and adapt existing functions. ArcGIS Model Builder and QGIS Graphical Modeler provide the option to create workflows without programming skill. The use of the python console allows for further automation and adoptions.

#ArcGIS ModelBuilder

ModelBuilder is an application for the construction and execution of simple workflows by creating, editing, and managing models. These models are workflows that consist of several geoprocessing tools and data that are connected that one tool's output will function as input for the next tool. Models contain tools, variables and connectors. *ModelBuilder* could be compared with a visual programming language for the construction of workflows. The created models can be saved as model tools and be shared with other users. Furthermore they can be exported to a python console and there they can be further extended with python code. Other advanced possibilities are the use of lists of values, iterators for loops, preconditions, feature or record sets, if-then-else logic or in-memory workspace. Moreover, *ModelBuilder* allows the integration of models or scripts within a model. Additionally the statistic package *R* can be run with the *ModelBuilder* environment (ESRI 2012).

#QGIS Graphical Modeler

The QGIS *Graphical Modeler* is the equivalent to ArcGIS's ModelBuilder. The application is used to create complex models that consist of several processes which can then be executed as one algorithm. The interface includes a working canvas for the model's visual representation, a menu bar with commands and a panel with tabs for inputs and algorithms for constructing the model. Models can be saved and shared with other users. By default they will be part of the toolbox. Equivalent to ArcGIS, models can be integrated in other models as algorithms. In fact they do not have a depth limit. Models can be automatically transformed to python scripts and there be adapted with python syntax. Beyond, models can be run as batch processes and thus several input sets can be processed without having to run the model all over again. The models are saved as JSON files (QGIS 2014).

 # Python Scripting

ArcGIS interactive Python interpreter with auto complete support, syntax highlighting and syntax checker consists of a Python section for the commands and a help section and enables the execution of geoprocessing tools and Python functionality. Additionally scripts and tools can be written in a python editor like *PythonWin* or *IDLE* and subsequently loaded in the python window in ArcGIS for Desktop. ArcGIS has the site package *ArcPy* which builds on the ArcGIS scripting module. It provides access to geoprocessing tools, functions, classes, and modules for the performance of geographic data analysis, data conversion, data management, and map automation with Python (Esri 2012). While the basis python modules are always available, specific *ArcPy* modules, like for instance "math" need to be imported first. Tools are licensed by *Esri* license [basic, standard, advanced] and the specific Extensions while Functions are part of the *ArcPy* module and thus are always available. Ever since the introduction of version 10.1 users have been able to program their own buttons and tools with the help of Python *add-ins*. Furthermore there are *python toolboxes* which represent geoprocessing toolboxes that are created entirely in Python (ESRI 2012).

As the source code for spatial statistic tools is available within a geoprocessing framework users can develop and share their individual tools and methods. Since August 2008 ESRI provides the *Geoprocessing Resource Center* (http://resources.arcgis.com/gallery/file/geoprocessing) which represents a library with documentation, sample scripts, and support for ArcGIS Python script tools (SCOTT & JANIKAS 2010: 39-40). As of February 2013 *ESRI* is also on *GitHub* (https://github.com/esri). User can browse open source code and get samples, templates, and viewers which were programmed by other users with APIs and different programming languages like python, JavaScript or C# (GitHub, Inc. 2014).

QGIS has an integrated Python console which can be accessed via the plugin menu. It opens a non-modular utility window with auto complete support, syntax highlighting and adjustable font settings. For interaction with the QGIS environment there is the *qgis.utils.iface* variable, which is an instance of *QgsInterface*. It allows access to the map canvas, menus, toolbars and other parts of the QGIS application. As QGIS is open source and the plugins are based on python and C++, there is a collection of the tool's python codes in the PYQGIS Cookbook (http://docs.qgis.org/testing/en/docs/pyqgis_developer_cookbook/). Additionally there is a full QGIS API reference for documentation of the QGIS libraries' classes for users interested in writing their own plugins (http://www.qgis.org/api/). The Pythonic QGIS API is almost identical to the API in C++ (QGIS DEVELOPMENT TEAM 2014).

Additionally, there is an online library with models and scripts that were written by users. These can be downloaded instantly within the QGIS interface similar to the installation of plugins with the Processing resources manager.

7.5 Visualization and Mapping

As the cartographic functions in ArcGIS and QGIS are very complex, CartoEvaluation Method was applied for the measurement of their functionality. The full evaluation schema can be viewed in the Annex.

#Functionality

In CartoEvaluation Method ArcGIS for Desktop 10.2.2 scored 83.56% out of 100% while QGIS scored 76.08% for cartographic functionality. ArcGIS had better results than QGIS for all four main goals, *Map Composition, Map Symbols, Cartographic Methods,* and *Map Syntax*. The biggest difference lies in ***Cartographic Methods***.

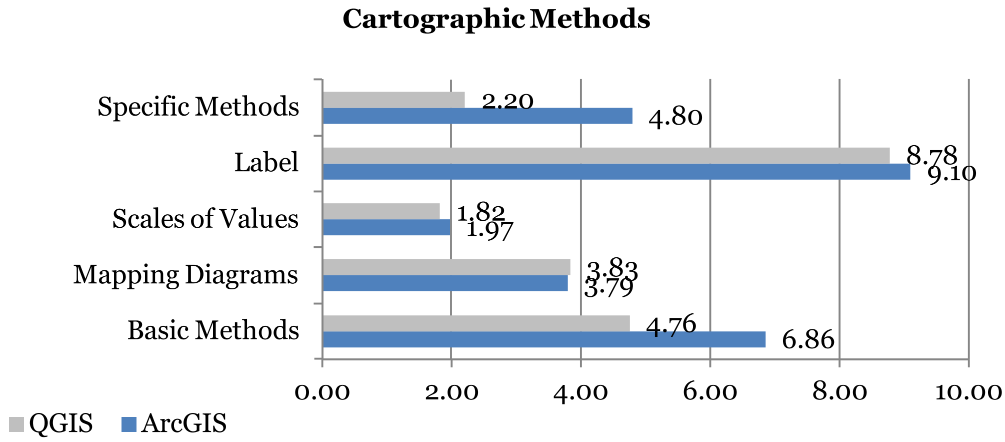


Figure 16 Ranking of Cartographic Methods according to CartoEvaluation Method

Here QGIS only reached 21.39 points while ArcGIS scored 26.63. In *Basic Methods* QGIS only reaches two thirds of the points that ArcGIS does. Examples for functionalities which QGIS does not provide but ArcGIS does are for instance the creation of different isolines. In the *Specific Methods* QGIS ranked even lower with 2.2 points compared to ArcGIS 4.8 points. Missing functions are the representation of 3D data and different forms of representations for georeliefs. Functionality which is not available in either of the GIS software is the creation of anamorphosis. In the categories *Label*, *Scales of Values,* and *Mapping Diagrams* however, the two programs are comparable.

	ArcGIS	QGIS	Max Points
Map Construction	**12.90**	**11.40**	**15.00**
Map Outline	2.70	2.70	3.00
Reference System of Map Face	3.20	3.20	4.00
Transformation Map Outline	3.20	2.20	4.00
Metadata Map Construction	2.00	2.00	2.00
Cartometry	1.80	1.30	2.00
Map Symbols	**30.60**	**29.90**	**35.00**
Pattern Book	1.20	1.20	1.50
Point Symbols	7.60	7.60	8.00
Line Symbols	7.60	7.50	8.00
Area Symbols	7.60	7.60	8.00
Localisation of Map Symbols	0.70	0.30	3.00
Color Setting	5.90	5.70	6.00
Metadata Maps Symbols	0.00	0.00	0.50
Cartographic Methods	**26.53**	**21.39**	**35.00**
Basic Methods	6.86	4.76	8.00
Mapping Diagrams	3.79	3.83	8.00
Scales of Values	1.97	1.82	3.00
Label	9.10	8.78	10.00
Specific Methods	4.80	2.20	6.00
Map Syntax	**13.53**	**13.38**	**15.00**
Intracomposition Design /Layout of Symbols	1.20	1.20	1.50
Map Layers	3.00	3.00	3.00
Extra composition - Map Arrangement	1.60	1.60	2.00
Title and Colophon	0.50	0.25	0.50
Legend	4.33	5.00	5.00
Map Scale	0.90	0.70	1.00
Additional Composition Elements	2.00	1.63	2.00
Total	**83.56**	**76.08**	**100.00**

Table 12 Results of CartoEvaluation Method with ArcGIS 10.2.2 and QGIS 2.6

Both programs show good cartographic possibilities for ***Map Symbols*** with 30.60% (ArcGIS) and 29.9% (QGIS) from 35 possible points. ArcGIS has slightly more cartographic possibilities in the categories *Color Setting, Localisation (→Placement) of Map Symbol,* and *Lines Symbols*. In the category *Localisation of Map Symbol,* QGIS for instance does not provide the option to avoid the collision of different symbols. An example for missing *Color Settings* is the fact that in ArcGIS the color codes can be set in RGB, HSV, and CMYK while QGIS only works with RGB and HSV color codes. In the category *Line Symbols* it is lacking the possibility to set different endings for the line symbols. In the categories *Point Symbols*, *Area Symbols* and *Pattern Book* both software are equal. Concerning the options for the ***Map Construction*** the software are almost even with 11.4 [QGIS] and 12.90 [ArcGIS]. They show the same functionalities for *Map Outline*, *MapReference System of Map Face* and

Metadata about Map Construction. However, ArcGIS has more functions for the *Transformation of Map Outlines* and in *Cartometry*.

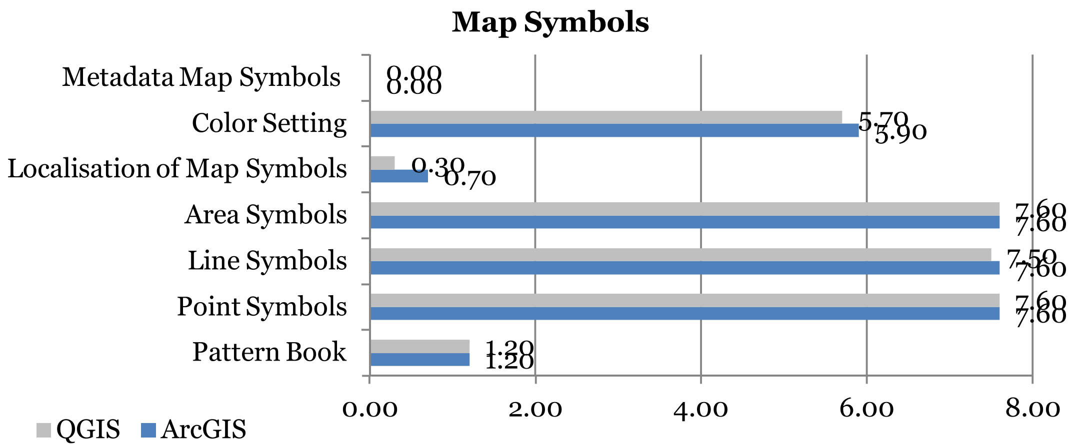


Figure 17 Ranking of Map Symbols according to CartoEvaluation Method

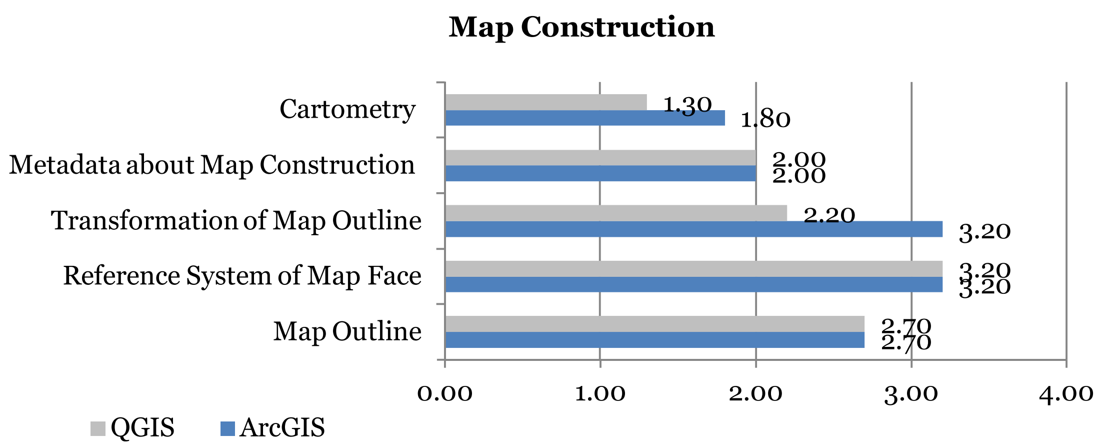


Figure 18 Ranking of Map Construction according to CartoEvaluation Method

In ***Map Synax***, thus the Layouting of the Map ArcGIS is stightly ahead of QGIS with 13.38% compard to 13.53%. The generation of the *legend* and the *Layout of Symbols* which describes the overall design and layout of symbols in the map face, as well as the *Composition* which includes the general graphic arrangement of the map elements, have comparable options. In the category *additional composition elements* which encompasses for instance the north arrow, text, tables, graphs, picutures, side map or multimedia elements, ArcGIS is in the lead as it holds the option to insert graphs or diagrams, which QGIS does not. Also for *Map Layers, Map Scale* as well as *Titel and Colophon*, ArcGIS provides a small advantage because it can for example create a colophon and has more options for formatting the scale bar.

The evaluation of ArcGIS and QGIS cartographic functions with CartoEvaluation Method showed that ArcGIS generally provides more options. However there are several cartographic features that were not considered in the evaluation manual. As an example blending modes can mentioned. QGIS provides 13 different blending modes which are comparable to those of graphic programs like lighting, screen, or dodge while ArcGIS does not have a comparable feature.

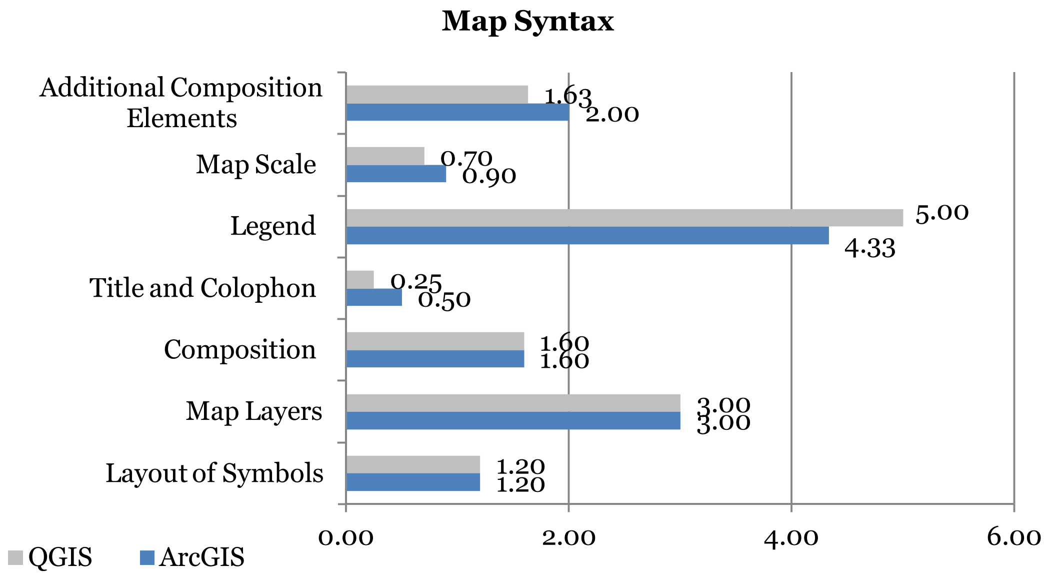


Figure 19 Ranking of Map Syntax (Map Design) according to CartoEvaluation Method

Another aspect which is not considered in CartoEvaluation Method is export options for the maps and their compatibility with other programs. This is an important point because for the design of high quality print maps neither ArcGIS nor QGIS are an appropriate choice as GIS software is designed for data processing and spatial data analysis rather than cartographic design. Therefore maps are usually pre-designed in the GIS with the results from the spatial analysis and are then finalized in a graphic program. For ArcGIS the proprietary graphic suite *Adobe Illustrator* is usually the first choice while QGIS works best with the open source *Inkscape*. QGIS maps can be exported as .svg files and loaded into *Inkskape* allowing the information of the different layers to remain available. Furthermore QGIS is compatible with the open source graphic programs GIMP for image processing.

Export Formats	ArcGIS 10.2.2	QGIS 2.6
PDF	yes	yes
SVG	yes	yes
AI	yes	no
EMF	yes	no
EPS	yes	no
BMP	yes	yes
JPEG	yes	yes
PNG	yes	yes
TIFF	yes	yes
GIF	yes	no
ICO	no	yes
PPM	no	yes
XBM	no	yes
XPM	no	yes

Table 13 Export Formats for Maps in ArcGIS and QGIS

#Usability

CartoEvaluation Method exclusively analyses the functionality of GIS programs and does not include other software quality attributes like for instance usability which also plays a crucial role for map design. In both programs *Map symbols* and *Cartographic Methods* can be accessed through the layer properties. In QGIS they are subdivided in the categories *Style, Label* and *Diagrams*, while in ArcGIS the categories are *Display*, *Symbology* and *Labels*. QGIS works with symbols and menu selection while ArcGIS only has menu selection. Both programs provide visual feedback. However, the functionalities are often only accessible through several sublevels in ArcGIS. While in QGIS all cartographic functionalities can be accessed through a maximum of 2 windows, it can however be up to 5 in ArcGIS. For instance if a user wanted to change the symbology of an area's outline from a solid line to a dotted line the paths would be under the following conventions:

[]	*New window opening up,*
→	*Mouse Click on Icon/Text Field*
:	*Drop-down list*

QGIS:

[Layer Properties] → *Style* → *Simple Fill* → *Border Style: Dot line*

ArcGIS:

[Properties] → *Symbology* → *Features/Single Symbol* → [Color Symbol Selector] → [Symbol Property Editor] → [Outline Symbol Selector] → [Symbol Property Editor] → *Style: Dotted*

The action can be implemented in QGIS in one window, while ArcGIS will open up five.

The *Map Syntax* is done in ArcGIS in the *Layout View* which complements the *Data View* in a map document. In QGIS maps are designed in an additional *Print Composer* window. Thus several maps can be created from one project in QGIS while in ArcGIS a new map document needs to be saved for each print map. Another consequence of QGIS separate *Print Composer* Window is the fact, that it will open a new menu that contains all the functionalities for map design while in ArcGIS the functions are selected from the main menu. ArcGIS has a selection menu with symbol and text while in QGIS the functions are directly available as tool bars with symbols. Text will show as hover effect.

Other mapping functions in ArcGIS are more hidden. Changes of the map's layout from landscape to portrait are implemented in the *print settings* in ArcGIS while in QGIS this action is done within the *print composer*. For the *Map Syntax* functionality ArcGIS also has several windows with sublevels, while QGIS provides all functions within a single window.

Furthermore QGIS provides some features of graphic programs. These are alignment and snapping function, as well as the option to lock and unlock elements. Furthermore it has an integrated *command history* window that enables the undo and redo of commands. Additionally the user can to drag and drop colors to different fields and to copy and paste styles in-between layers. In ArcGIS Layer Files can be saved which contain the layer's symbology information and thus allow transferring the style to other layers.

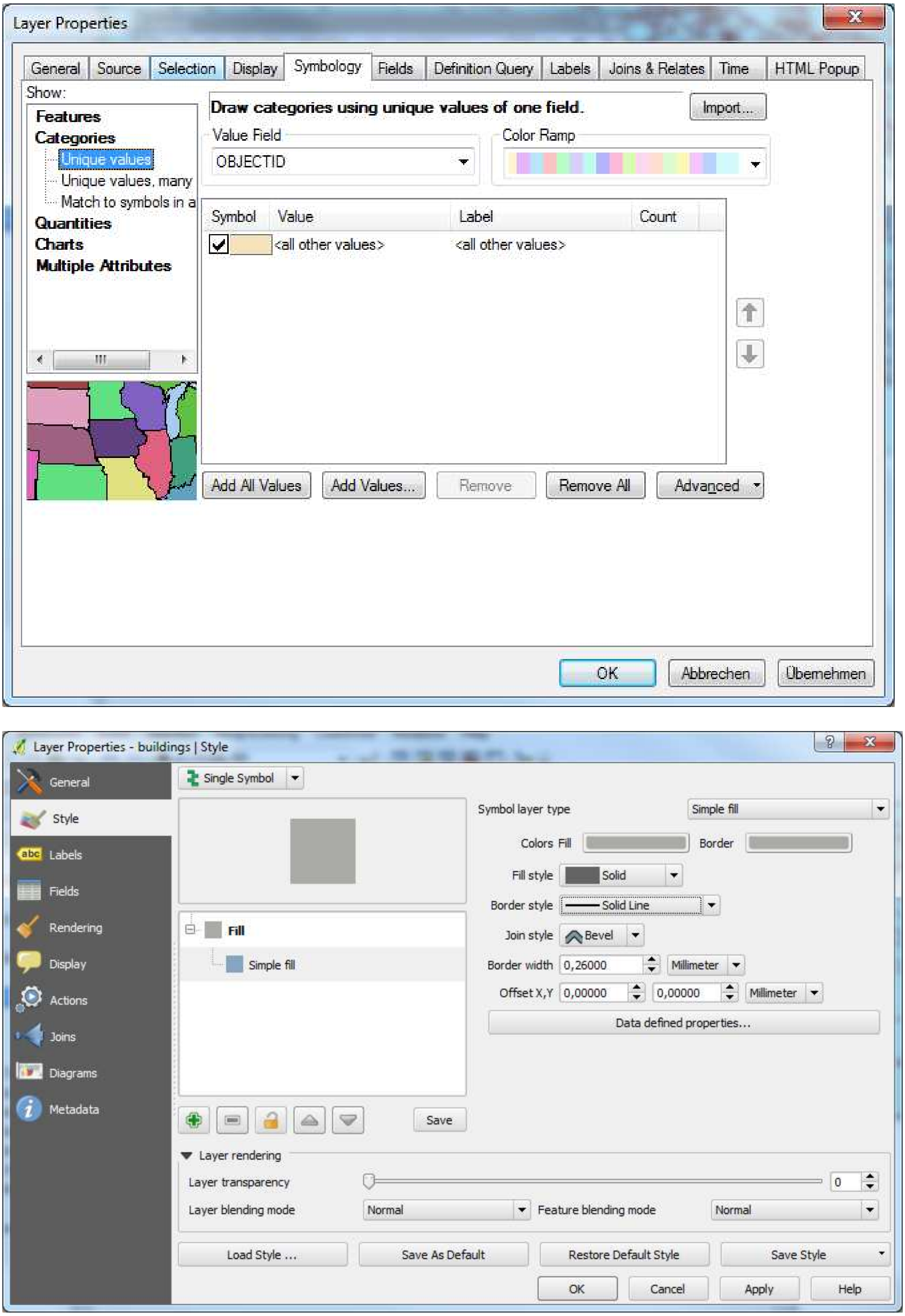


Figure 20 Screenshot of ArcGIS Layer Properties – Symbology [top] and QGIS Layer Properties – Style [bottom]

8 Test Analyses

In this chapter several test analyses will be implemented with ArcGIS and QGIS. The analyses were chosen based on the theory and cover spatial planning issues concerning sustainable development in different cities and regions in Germany and Austria.

8.1 Catchment Area Analysis for Green Space

As discussed in the theory, urban green areas provide several ecologic and social functions for urban dwellers. In the city of Nürnberg 40 percent of the territory is covered by farming, forests, and green areas (STADT NÜRNBERG 2014). A crucial point concerning green areas is however their accessibility.

TASK

In this analysis the provision of parks within the city boundaries of Nürnberg will be analyzed. Therefore different sets of Buffer with varying distances will be calculated. The following questions should be answered:

- Which housing areas lie within a 200m, 300m, or 400m radius of a park?
- Which housing areas are located within a variable distance of a park depending on the park's size [*park size/100*]?

TOOLS

ArcGIS: *Buffer, Multi-ring Buffer* [Analysis]

QGIS: *Fixed distance Buffer, Variable distance Buffer* [Vector Tools], *Shapes Buffer* [SAGA]

DATA

Land use: ***landuse.shp, roads.shp, buildings.shp, names.shp*** [Data Source: OSM]

- CRS: GCS_WGS_1984, Datum: D_WGS_1984, unit: degree
- Extend: Top: 49,780960 dd, Left: 10,000301 dd, Right: 11,599250 dd, Bottom: 48,868881 dd

Administrative Boundaries: ***gmd_ex,shp***[1] [Data Source: BAYERISCHE VERMESSUNGSVERWALTUNG 2013]

- CRS: DHDN Grauß Krüger Zone 4 (EPSG: 31468), units: m
- Extend: Top: 4635355.53, Left: 4283564.83, Right: 5604906.51, Left: 5238393.79

DATA PREPARATION

[1] „Datenquelle: Bayerische Vermessungsverwaltung – www.geodaten.bayern.de"

1. ***Project*** layer to CRS: DHDN Grauß Krüger Zone 4 (EPSG: 31468)
2. ***Select*** feature Nürnberg in *gmd_ex*.shp and ***create new feature class*** Nuernberg.shp
3. ***Clip*** landuse.shp, roads.shp, buildings.shp, names.shp to extend of Nuernberg.shp

WORKFLOW

ArcGIS

1. ***Select*** [Analysis] parks from landuse.shp
2. ***Create new layer from selected features*** with parks and export it as .shp file (automatically creates Shape Area field)
3. Create ***Multi-ring Buffer*** [Analysis] with 200, 300, 400m distance around parks.shp
4. ***Add field*** distance [short integer] and ***calculate*** values [Area/100]
5. Create ***Buffer*** [Analysis] based on attribute distance
6. ***Select by location*** the buildings that intersect the generated Buffer zones

QGIS

1. ***Select*** parks from landuse.shp
2. ***Duplicate*** layer, ***switch*** selection and ***delete*** selected features
7. Create three separate ***Fixed distance Buffer*** with 200, 300, 400m distance around parks with area
3. Select Buildings that intersect the generated Buffer zones
4. Apply Buffer [SAGA] with distance bases on Area field and scaling factor

RESULTS

Both programs show similar results for the size of the buffers. The number of the buildings which lay within the buffers is different though.

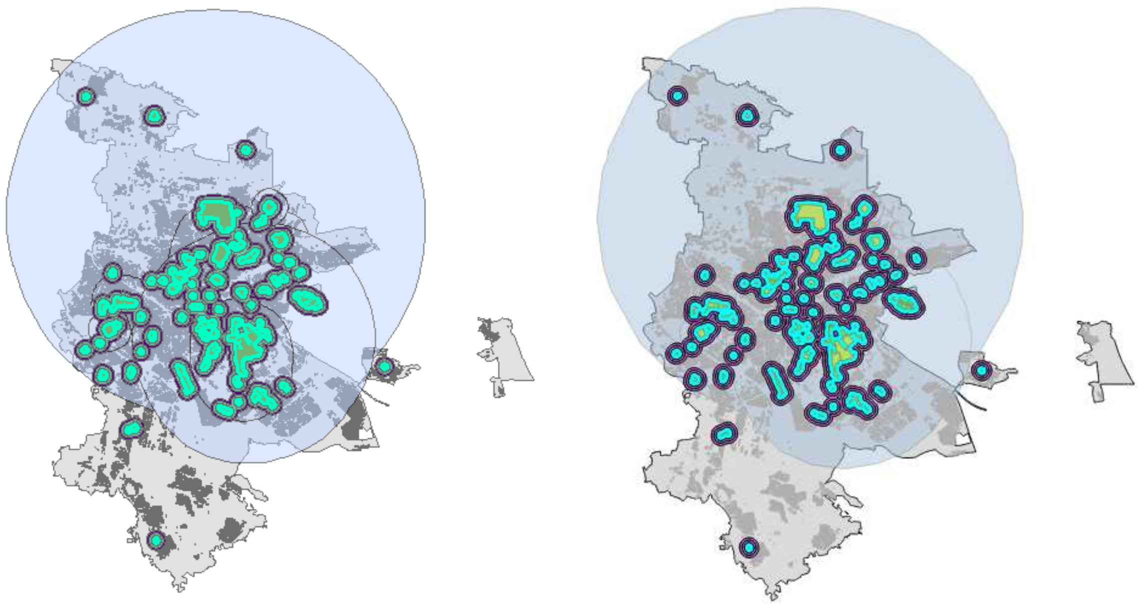


Figure 21 Buffer with variable distance in ArcGIS [left] and QGIS [right]

However, after projecting and clipping the buildings layer, ArcGIS layer has 73.240 features and QGIS only 70.934. Consequently the absolute numbers as well as the percentages differed as can be seen in the following table.

	ArcGIS (73240)		QGIS (70934)	
	Absolute	Percentage	Absolute	Percentage
Park within 200m	14831	20,3%	14560	20,5%
Park within 300m	23181	31,7%	22696	32,0%
Park within 400m	30146	41,2%	29404	41,5%
Park within Variable Distance	55274	75,5%	53056	74,8%

Table 14 Supply of Green Areas

Functionality

Both software rank about equal in functionality. ArcGIS has a multiple ring buffer in which several distances can be added and computed as one shape file. SAGA can also create several buffer zones. However, the absolute distance was always 100m although 400 was specified in the settings. Consequently the different distance buffers were created separately and combined with the geoprocessing function *Union*. ArcGIS has a buffer to create variable distances based on a field. The field values cannot be scaled, though that is possible with SAGA and GRASS buffer. Thus a separate distance field had to be added and calculated in ArcGIS.

For *accuracy* it needs to be considered that QGIS Buffer can be created with an internal algorithm as well as SAGA GIS and GRASS GIS algorithms. In QGIS the shape depends of the number of segments, with 1 segment creating a square. SAGA GIS will produce round buffers.

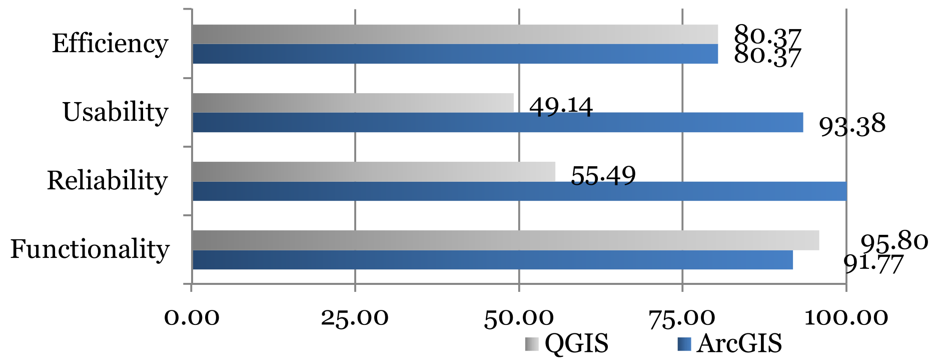


Figure 22 Quality Attributes for Catchment Area

Catchment Area	Weight	ArcGIS	QGIS		Weight	ArcGIS	QGIS
Functionality	**100.00**	**91.77**	**95.80**	**Usability**	**100.00**	**93.38**	**49.14**
Suitability	44.00	39.80	39.80	Understandability	7.19	7.19	7.19
Accuracy	44.00	44.00	44.00	Learnability	64.91	64.91	22.47
Interoperability	4.02	0.00	4.02	Operability	27.90	21.28	19.48
Compliance	7.97	7.97	7.97				
Reliability	**100.00**	**100.00**	**55.49**	**Efficiency**	**100.02**	**80.37**	**80.37**
Maturity	87.50	87.50	42.99	Resources	25.00	25.00	25.00
Fault Tolerance	12.50	12.50	12.50	Time	75.02	55.37	55.37

Table 15 Quality Attributes for Catchment Area

Usability

ArcGIS ranks higher in *usability*. While the understandability is the same, ArcGIS has advantages in *learnability* as well as *operability*. ArcGIS Buffer are easy to find and are well documented in the help. In fact a description for each setting is integrated in the tool's window. In QGIS multiple buffers from QGIS, GRASS GIS, and SAGA GIS can be used which complicates the choice. QGIS internal buffers do not have documentation, neither in the program, the official help, nor in the internet. The use of the "segment" setting needs to be discovered by trial and error.

Reliability

ArcGIS scores higher for reliability with 100 to 45.49%. All buffers could be run successfully on the first try, while SAGA's buffer created unexpected outcome for the multiple buffer zones. Finally the Buffer had to be created separately.

Efficiency

Regarding *efficiency* both programs are equal. While QGIS is slower in creating multiple buffers, ArcGIS is less straightforward in creating buffer by variations of an attribute field. For speed both programs are quick. The variable distance buffer took 1 sec in each case.

ArcGIS multiple ring buffer took 20 sec. while the single Buffer in QGIS were calculated within a second.

FURTHER POSSIBILITIES

QGIS has the option to *Buffer by percentage* [plugin]. This tool will create Buffer polygon features in the way that the buffered zone is a specified percentage of the original area. Another way to determine a catchment area would be to calculate isochrones. This can be done with the extension Network Analyst in ArcGIS through the creation of a new service area. In QGIS isochrones can only be calculated with pgRouting, which extends PostGIS / PostgreSQL geospatial database to provide geospatial routing functionality (PG ROUTING COMMUNITY 2014).

8.2 Density Analysis with Time Enabled Maps

The population of Vienna has been growing since the 1990ies. In October 2014 the number of residents hit the 1.8 million mark, the highest number since 1934. In the last 14 years the number of residents grew by 250.000 people. It is projected that the city will count 2 Million residents in 2029 and up to 2.11 Million residents in 2044 (MAGISTRAT DER STADT WIEN 2014a). This population growth holds great potential for the economic development of the city but also represents a challenge for spatial planning. These include questions on housing, transportation and other public services. Therefore it is necessary to determine the areas in which the population density will raise.

TASK

The idea is to create a time enabled map that shows the evolution of population density from the present and projects them into the future. To raise the accuracy of population density uninhabited areas like green and open spaces as well as water will be excluded.

In ArcGIS ***TimeSlider*** is part of the layer properties. Once the layer has been time enabled in the time tab, data can be visualized by using the time slider. The time-enabled layer can be shared as a map service or exported as video (ESRI 2014).

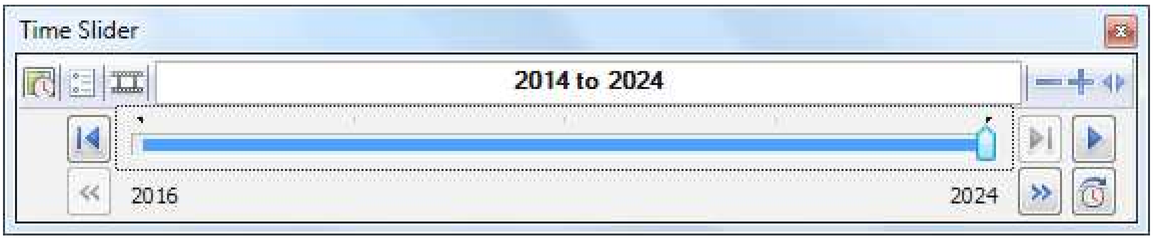


Figure 23 ArcGIS Time Slider

QGIS ***TimeManager*** is an experimental plugin, which means that it is “unsuitable for production use” and should be considered “incomplete” or a “proof of concept” tool as it is still in an early stage of development. The tool installs time controls which can be used to animate vector features with the help of a time attribute. Animations can be produced directly in the map window and subsequently be exported as image series (QGIS 2014).

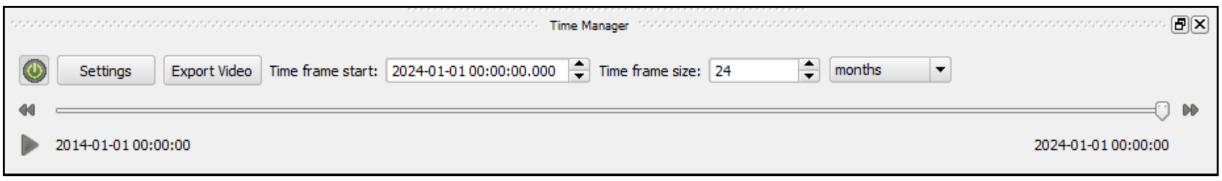


Figure 24 QGIS Time Manager

- Population Density under consideration of Green Spaces, Open Spaces and Water Areas
- Population visualized as density (area symbol) and total population (Point Symbol)
- time series from 1914-2024 in intervals of 2 years
- Create Video with 10 sec and display of years

DATA

Geodata:

- Vector Layer Green Spaces.shp, Water Areas.shp, Statistical Districts.shp, Districts.shp [WSG84] [Data Source: OGD Wien]

Other Data:

- CSV: Population Prognosis 2014-2024 based on Statistical Districts [Data Source: OGD Wien]

DATA PREPARATION

1. **Project files** from WSG to MGI/ Austria Lambert [EPSG:31287]
2. Add ***new field*** for StatisticalDistricts.shp with subdistrict codes

WORKFLOW

ArcGIS

1. ***Erase*** Green and Open Spaces and Water Areas
2. Prepare xls. File with Total Population data for years 2014-2024 (every second year) in columns
3. Import popchange.xls and ***join*** it to StatisticalDistricts.shp
4. ***Calculate*** Area in km² and Densities [Population/Area] for the years 2014-2024
5. ***Transpose*** fields with Transposed Field = *Years* (format YYYY) and Value Field = *Population* so that the population data for the different years is stored in rows instead of columns
6. ***Copy*** file to ***Visualize*** density data as area symbol with graduated colors and total population as a pie chart
7. ***Time Enable Layer*** with the settings: interval 10sec, display of years, time-step intervals 2 years
8. ***Export*** as video [data format: .avi]

QGIS

1. Remove the ***Difference*** of Green and Open Spaces and Water Areas from StatisticalDistricts.shp
2. ***Create*** one CSV file (populationYYYY.csv) per year for the years 2014-2024 (every second year) with the total population of the corresponding years [format: YYYY-MM-DD]
3. Create a ***feature class*** from StatisticalDistrictsYYYY.shp for each year that will be displayed
4. Import the popchangeYYYY.csv files with *Add delimited text layer* and ***join*** them to the corresponding StatisticalDistrictsYYYY.shp
5. Merge all StatisticalDistrictsYYYY.shp to one file StatisticalDistricts.shp
6. ***Calculate*** Area in km² [area/1000000] and Densities [Population/Area] for the years 2014-2024
7. ***Visualize*** density data as area symbol with graduated colors and total population as

pie chart

8. Install Plugin and create ***Time Enabled*** Map with interval 10sec, time frame size: 24 month, looping,
9. ***Export*** as video

RESULTS

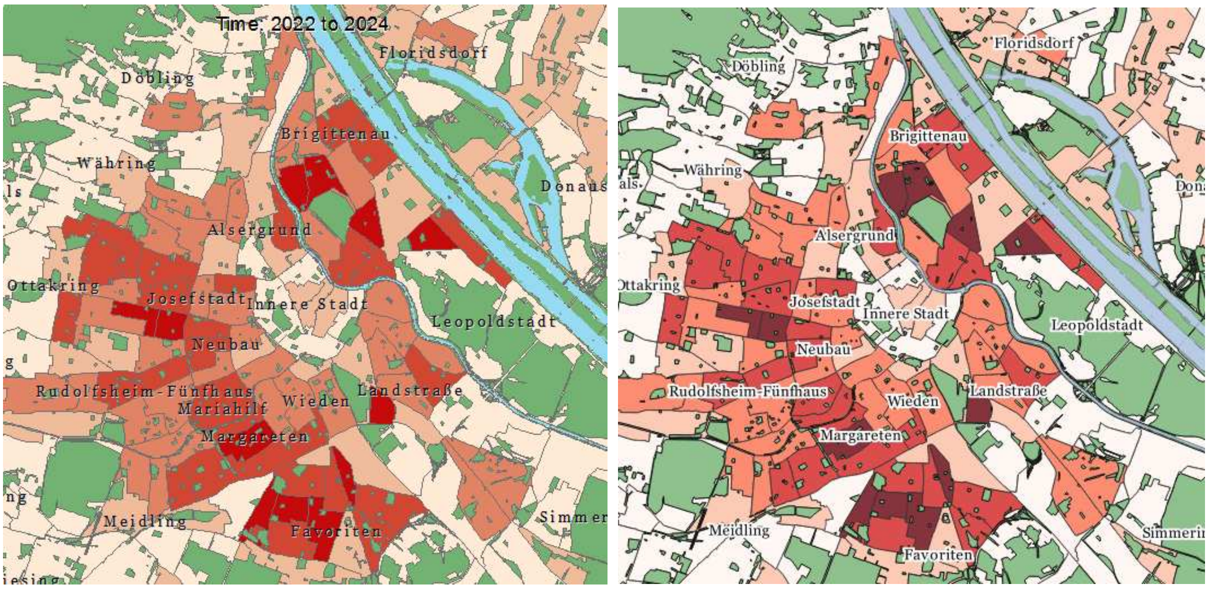


Figure 25 Population Density in 2024 with ArcGIS [left] and QGIS [right]

Despite the small time span of only 10 years, both maps show an intensification of the density in Vienna between 2014 and 2014. The classification is equal during the years because the maps were initially displayed equally with area symbols of equal intervals with the same classes in both programs. The class of neighborhoods with the highest densities of 34383 to 42977 residents per km² grows from 4 to 12 neighborhoods.

In ArcGIS the results only show the changing population either as area symbol or point symbol. Finally the area symbol was chosen. QGIS could display both datasets at the same time. However the transition between two years is not fluent in QGIS. The layers reload, showing a white screen in between, especially when area symbols and point symbols are visualized at the same time.

The required time setting of 20 seconds could not be fully implemented in QGIS. The duration for each frame will not be the same when the default setting of 3000 milliseconds is changed to run slower or faster.

In ArcGIS the time enabled map could be successfully exported as a video in .avi format, while in QGIS it is only possible to export the single frames as raster data (.png).

Functionality

The two programs did not score high for functionality, neither in *suitability*, nor in *accuracy*. Both programs provide functionality to play, pause, fast forward, rewind, loop, play backwards, and adopt the interval and the speed of the animation. Anyhow, ArcGIS cannot display area charts and pie charts in the same layer. Furthermore it is not possible to integrate several layers in the time slider. In QGIS both can be visualized simultaneously. However the section can only be exported as single raster datasets for each key frame in QGIS. In ArcGIS the map series was exported as video in .avi format.

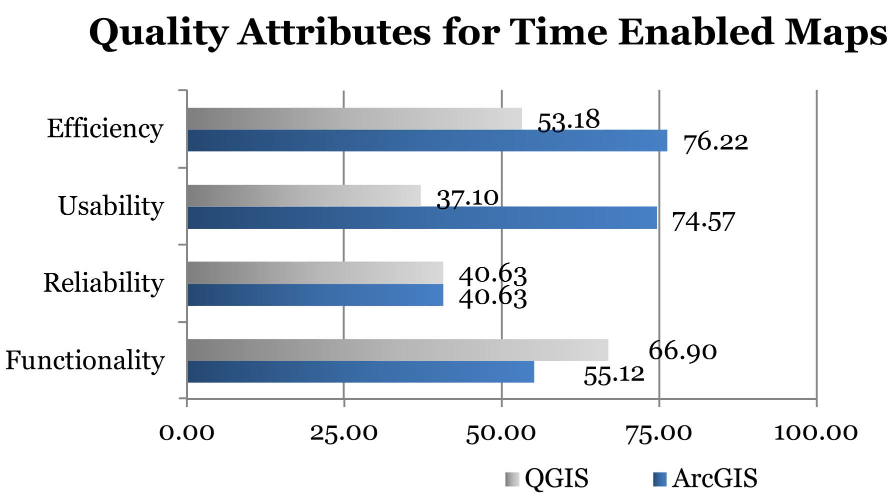


Figure 26 Quality Attributes for Time Slider [ArcGIS] and Time Manager [QGIS]

Usability

For the quality attribute of usability ArcGIS clearly is ahead of QGIS with twice as many points. The time slider is easy to find and its use is well documented. In QGIS however the functionality of *TimeManager* is not fully explained which made it score low in *learnability*. 7 different websites had to be consulted to figure out how it can be operated and most important how the data needs to be prepared. There is no documentation in the official help and the integrated help of the tool is merely a description and not an instruction. Furthermore there is no documentation in the German language available. In terms of *understandability*, TimeManager is harder to find compared to ArcGIS *time slider* as the plugin has to be downloaded first. Moreover it is necessary to activate the usage of experimental plugins.

For *operability* the two programs scored high as the interface is coherent and works with symbols. The control panel is comparable to that of standard audio equipment and can be used intuitively. However, a disadvantage of both programs is the lack of error messages in case of wrong data input which makes it cumbersome to detect the origin of any issues.

Reliability

ArcGIS and QGIS both scored low for reliability with only 41 points. In both cases the time function could not be implemented correctly on the first try but certain adoptations were necessary. Also the export of the video in ArcGIS could not be done successfully on the first try. No movement was shown and the intervals were not in accordance with the ones in the time slider. The data quality had to be adapted several times. The same is true for the settings, in particular those of speed and intervals. Additionally the two GIS software showed unexpected responses. No movement was shown although the layers were time enabled. For ArcGIS it was not possible to set the interval in the time tab of the layer properties, but it would automatically switch to months instead of years. The settings had to be entered in the time slider. Despite the required adoptions of the settings and data quality the features ran stable and no runtime errors occurred.

Efficiency

ArcGIS wins in terms of *efficiency* and has a special advantage in the category Time where it scores 51.2 points compared to 29.8 points in QGIS. The software provides the *transpose* function in the data management tools which enables to transform the joint data for all the years in one feature dataset in rows instead of columns so they can be read from the time slider. QGIS does not have such a function which makes it necessary to create a layer for each year, join the data separately, and copy the layers together.

	Weight	ArcGIS	QGIS		Weight	ArcGIS	QGIS
Functionality	**100.0**	**55.1**	**66.9**	**Usability**	**100.0**	**74.6**	**37.1**
Suitability	44.0	25.1	36.9	Understandability	7.2	6.8	0.4
Accuracy	44.0	22.0	22.0	Learnability	64.9	41.6	11.5
Interoperability	4.0	0.0	0.0	Operability	27.9	26.1	25.2
Compliance	8.0	8.0	8.0				
Reliability	**100.0**	**40.6**	**40.6**	**Efficiency**	**100.0**	**76.2**	**53.2**
Maturity	87.5	40.6	40.6	Resources	25.0	25.0	23.4
Fault Tolerance	12.5	0.0	0.0	Time	75.0	51.2	29.8

Table 16 Scores for Quality Attributes for Time Enabled Maps in ArcGIS and QGIS

FURTHER POSSIBILITIES

ArcGIS includes functionality for the creation of animations for view, layer properties and data through time. Examples are the movement through a scene along a path, varying layer visibility or the animation of tables, feature class layers, and netCDF layers in a graph (ESRI 2010).

QGIS does not provide further options for animation.

8.3 Network Analysis for Sustainable Transport

In the sense of sustainable mobility, the City of Vienna has set goals in their Master Plan on Traffic to promote public transport, biking and walking in the city, and reduce motorized private transport in return. Unit 2022 the ratio of public transport and motorized private transport should shift from 35/65 percent to 45/55 percent (MAGISTRAT DER STADT WIEN 2014b). The organization *Mobilitätsagentur* promotes walking and biking in the city. In 2013 the city celebrated the "Year of the Bike" where it hosted the largest yearly international biking conference *Velo-city* which should help to achieve the city's goal of raising the number of bikers until 2015 to 10 percent (MOBILITÄTSAGENTUR WIEN 2012).

TASK

In this analysis, the shortest transport routes and the corresponding travelling times of bikers, pedestrians/public transport users and car drivers will be compared with the help of a network analysis. The study area will be the 17th district in Vienna. It is suitable because it stretches from the inner city to the outskirts of Vienna and thus provides a differentiated topography and public transport stop density.[2]

TOOLS

- ArcGIS: *Build Network, Add Location, Solve* [Extension: Network Analyst]
- QGIS: *Road Graph* [Vector tools]

ArcGIS network analyst Extension *Build Network* creates a network consisting of line, and optionally point layers including attributes for costs (time & distance), hierarchies, direction, and restrictions. Hereby the shortest route between several points in a network can be found as a function of the specific network costs. The calculated path can be exported to a .shp-file.

QGIS integrated *Road Graph* core plugin finds the shortest path between two points on a line layer and draws the path over the road network. The shortest path can be calculated based on time and distance. The tool holds the possibility to include the direction and speed for each segment. The calculated path can be exported to a .shp-file.

The following criteria should be included in the network:

- Drivers cannot go against one-way streets, thus each network section contains a *direction*, either to-from or from-to with reference to the direction in which it was digitalized
- Bikers, Pedestrians, and Public Transport vehicles move independently from one-way streets
- The *speed* of drivers will be assumed with 30km/h respectively 50km/h according to the official speed limit but also the narrowness of the street
- The speed influences the *hierarchy*, consequently a street with 50km/h has hierarchy 1 and 30km/h hierarchy 2
- The *speed of bikers* will depend on the slope of the terrain, the driving direction and vary between 5 and 20km/h

[2] The Analysis is based on data of the lecture "Modellierung in der Geoinformation" at Universität Wien, WS 2012

- Bikers have different priorities concerning the choice of the frequented streets depending on the availability of bike lanes. Overall there are the three *hierarchies* separated into bike lane [1], bike lane on street, [2] and street [3]
- *Pedestrians* move with a *speed* of 3 to 5km/h depending on the aspect and the direction in which the person is moving
- *Busses* have the same *speed* as cars, while trams and the underground have the maximum speed of 30km/h
- There will be *stopping times* at the 78 public transport stops, with the following *stopping times*: trams 20 seconds, buses 10 seconds, and underground 15 seconds.
- The *network for public transport* users [publictransport.shp] and pedestrians [pedestrians.shp] is combined because public transport users switch to the pedestrian network in order to get to the public transport spots which are held in a point feature layer [stops.shp]

Difference in Height/100m	**Speed Bikers**	**Speed Pedestrians**
< -8m	10km/h	3km/h
-8m - -1m	20km/h	5km/h
-1m - +1m	15km/h	4km/h
+1m - +8m	10km/h	3km/h
> +8m	5km/h	2km/h

Table 17 Speeds for Bikers and Pedestrians

DATA

Geodata:

- Vector Layer: Roads.shp, line features including the attribute length and street names [Data Source: Universität Wien]
- Digital Height Model: DHM Wien [Data Source: Magistrat der Stadt Wien 2014a]
- District Borders Vienna: Bezirksgrenzen.shp [Data Source: Magistrat der Stadt Wien 2014a]

Other Data:

- Online City Map [Data Source: Magistrat der Stadt Wien 20014b]
- City Map "Wien" [Data Source: FalkVerlag 2008]

DATA PREPARATION

- The *height* values were extracted for each node of the vector layers from the DHM and afterwards the aspect of each line segment. The individual speeds of the different traffic participants per line segment were calculated with the help of the aspect and the direction of the aspect with reference to the segment's direction of digitalization.
- A *new point feature layer* stops.shp with 78 public transport stops for busses, trams, and the underground U6 was created

- The four layer Pedestrian.shp, Roads.shp, Publictransport.shp and Biking.shp were created from the initial Roads.shp layer and their specific attributes were added respectively and calculated according to Table 17
- A new point feature layer Routing Points with 8 locations was digitalized as a base for the Shortest Path Analysis

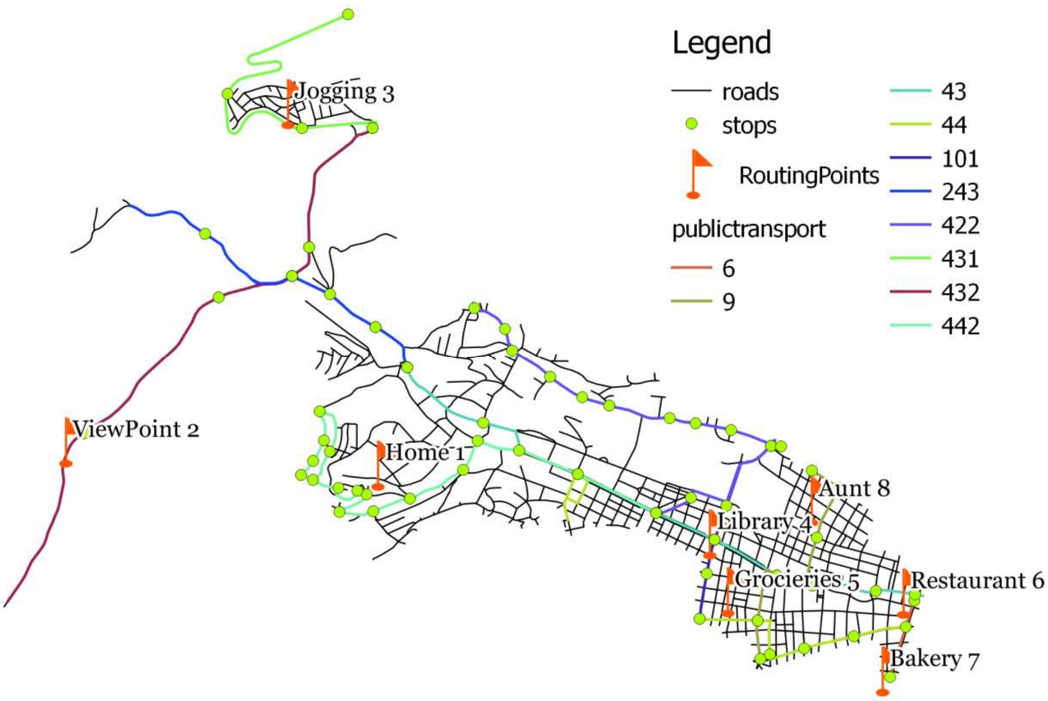


Figure 27 Routing Points for network analysis including Public Transport layer

Layer	Shape	Attributes
Roads.shp	Line	DriveTime [min] Oneway M [two-directions], FT [From-To], TF [From-To] DriveHierarchy [1,2] Speed [km/h] Meters [m]
Biking.shp	Line	BikeHierarchy [1,2,3], Meters [m] BikingTimeTF [min] BikingTImeFT[min]
Pedestrains.shp	Line	PedestrianTimeFT [min] PedestrianTimeFT [min] Meters [m] PedSpeed [km/h]
PublicTransport.shp	Line	PTSpeed [km/h] Meters [m]
Stops.shp	Point	StopTimeMin [min]

Table 18 Layer and attributes for Network Analysis

WORKFLOW

ArcGIS

1. ***Create*** *new FileGeodatabase, new Feature Dataset* (essential for networks) and import FeatureClasses
2. Activate ***Extension*** Network Analyst
3. ***Build Network*** **1** for *roads.shp* and *biking.shp* consisting of 2 separate classes including the attributes BikingTimeFT, BikingTimeTF, DriveTime, Meters, Oneway, BikingHierarchy, and DriveHierarchy, Speed [Network Analyst/Network Dataset]
4. ***Build Network 2*** for *pedestrian.shp* and *publictransport.shp* including *stops.shp*, consisting of one class as users can switch between using public transport and working. The attributes include PedestrianTimeTF, PedestrianTimeFT, Meters and PedestrianSpeed, PTSpeed and StoppingTimeMin [Network Analyst/Network Dataset]
5. Create ***new routes*** for each of the 3 traffic participants [Network Analyst]
6. ***Add new locations*** from RoutingPoints.shp to Network1/2 [Network Analyst/Analysis]
7. Find the shortest path between the different routes with ***Solve*** tool
8. ***Export*** new layer with lengths and time of shortest path as shapefile

QGIS

1. ***Import*** Layers
2. Activate panel ***Shortest Path*** and ***Snapping*** function
3. Fill attributes time unit, distance unit, topology tolerance, layer, direction field and speed field in ***Road Graph Settings*** [Vector/RoadGraph]
4. Set ***Start*** and ***Stop*** Point and ***calculate*** shortest path. This step has to be repeated for all points participating in the search
5. ***Export*** new layer with lengths and time of the shortest path as shapefile. New path segments can be added to the corresponding path shapefile.

RESULTS

	ArcGIS Time [min]	QGIS Time [min]	ArcGIS Length [m]	QGIS Length [m]
Road	22:17	22:59	16535	16615
Biking	82,14	75,16	19027	18790
Public Transport	230,97	66,45	26074	21714

Table 19 Results of Network Analysis

Concerning the *shortest path for drivers*, which was the only one where ArcGIS and QGIS had exactly the same attributes, namely speed, meters, and one way streets, the time difference is 42 seconds (3.2%[3]) of the complete time. The derivation of the length is 80.5m (0.5%). In both programs the routing could not find stop 6 and stop 7 in the road.shp network which is correct as the car cannot navigate against one-way streets. Moreover, there are two derivations in the pattern of the shortest path for drivers which can be viewed in the following chart. However, both possibilities are correct in terms of one-way streets.

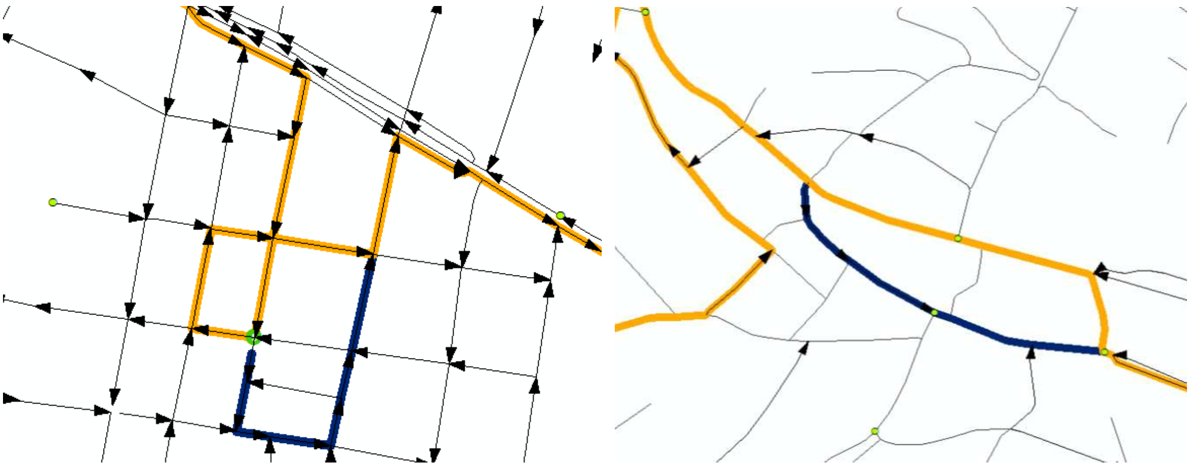


Figure 28 Derivations in shortest driving route ArcGIS [blue] and QGIS [yellow]

The times for the pedestrian and biking route cannot be compared because the programs worked with different data. As QGIS cannot work with differentiated times for directions, the aspect of roads could not be considered but average speed values had to be used. They were 4km/h for pedestrians and 15km/h for bikes. The biking route differs in two locations which can be viewed in the figures below. The first divergence is not connected to the existence of a bike path and thus the inclusion of hierarchies in the network. The second example shows that the divergence exists because ArcGIS Network Analyst took the existence of a biking lane and thus the classification of the street as hierarchy 1 into account.

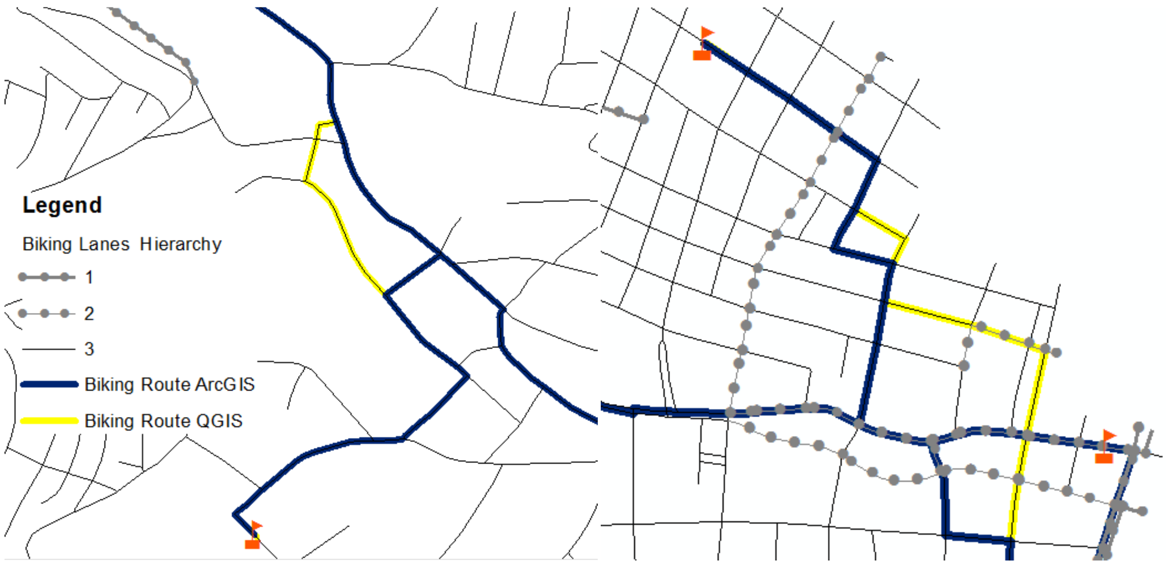


Figure 29 Divergences in Biking Routes of ArcGIS [blue] and QGIS [yellow]

[3] *The Percentages are calculated in relation to the value of ArcGIS*

The programs calculated different routes for the public transportation routes. The huge time difference of 165 min (71.2%) indicates that there was a mistake in ArcGIS switching between the public transport layer and the pedestrian layer. Also compared to the values of drivers and bikers QGIS value seems correct.

In ArcGIS network analyst the shortest path obviously wasn't calculated in some cases as indicated in the example below. The path makes a loop to the west before leading east. Furthermore there is a section in which the ArcGIS route takes a loop which cannot be explained by the routing of the public transportation network (Figure 30. As QGIS cannot switch between two line layers, the segments for pedestrians and public transport had to be calculated separately, and subsequently exported to one shapefile. The result is a different in length of 4359m (16.7%) for the two networks.

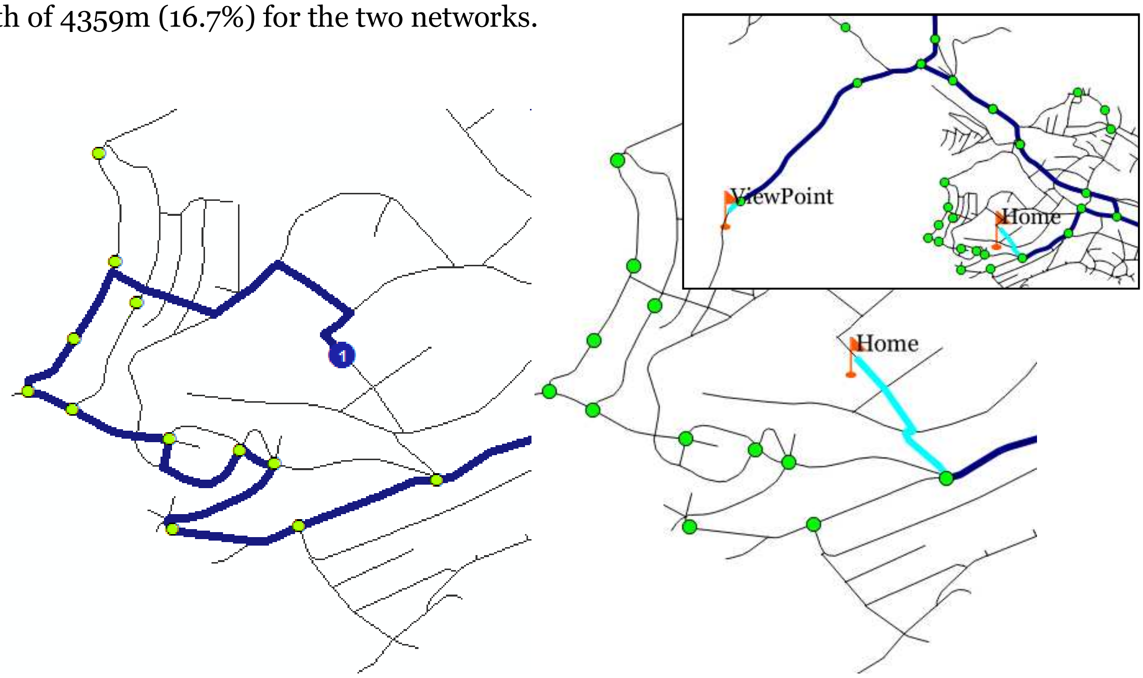


Figure 30 Public Transport Network in ArcGIS [left] and QGIS [right] with Overview Map

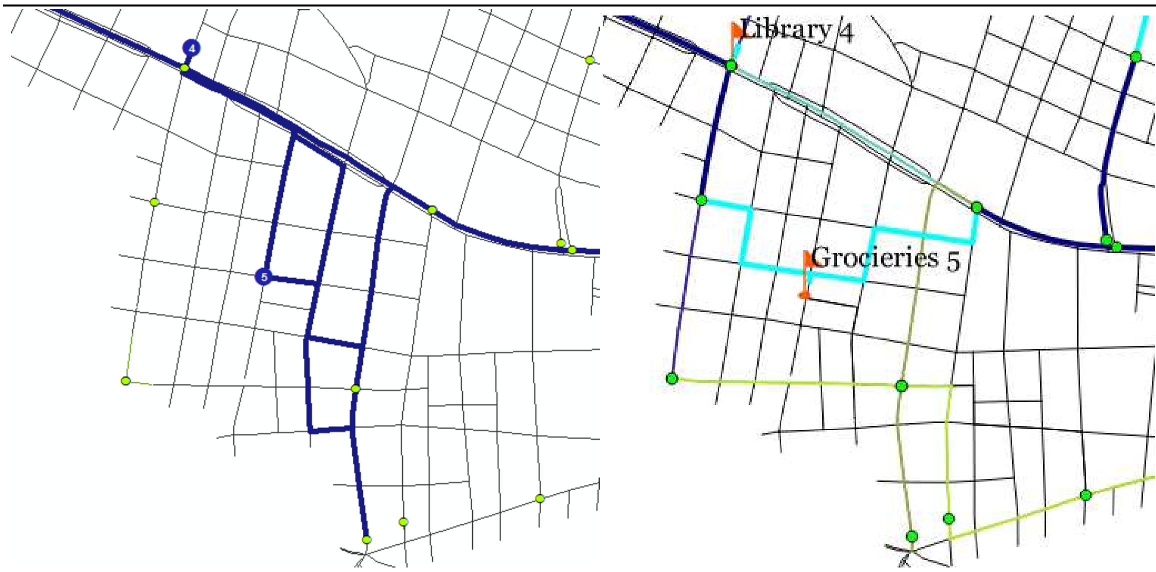


Figure 31 Public Transport Network Routing in ArcGIS [left] and QGIS [right]

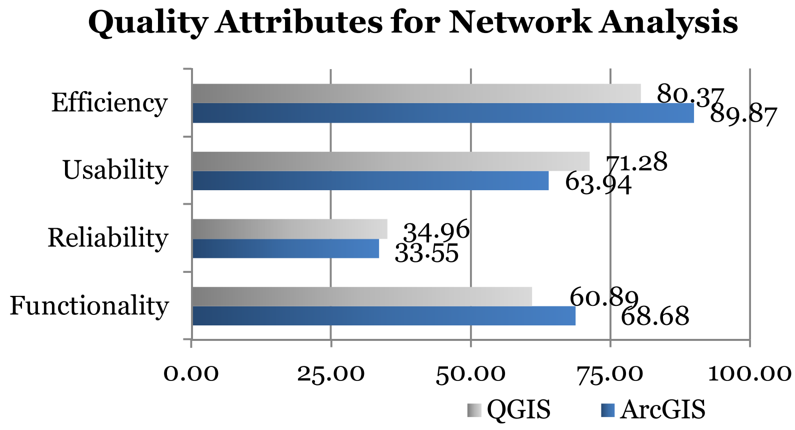


Figure 32 Quality Attributes for Network Analysis

Functionality

In the category *functionality* QGIS ranks slightly higher than ArcGIS. This is due to the fact that it scores full points for *accuracy* while ArcGIS couldn't calculate the combined public transport and pedestrian network correctly. However ArcGIS can include more attributes in the network analysis and thus has a higher *suitability*. Both programs can include distance, speed, and directions. However, in QGIS several criteria could not be included in the network analysis. First there is no possibility to include hierarchies in the network and second, QGIS cannot incorporate two different speed values which dependent on the direction of movement. Thus it was not possible to include the information whether a pedestrian or biker is moving uphill or downhill. Third, QGIS cannot include the stopping times at public transport stops. Moreover ArcGIS includes the height of nodes when constructing the network. In this way it takes into consideration that streets are not always connected when their path cross as for instance at bridges.

A negative aspect of ArcGIS compared to QGIS is the possibility for further use of the data. While in QGIS each route section between two points of interest is stored as an individual feature with lengths and time, in ArcGIS there will only be one feature in the exported vector shapefile with the total lengths and time. Although ArcGIS produces a detailed route navigation including street names, turns, times, and the option for viewing the section in a interactive map, this result cannot be exported as vector layer but only txt, html or xml files.

Reliability

Concerning *reliability* both programs score rather low which can be explained with the frequent defects due to the complexity of a network analysis and. Both software scored 0 for fault tolerance. With ArcGIS the construction of the network for analysis out of the basic layers caused several problems. The public transport stops could not be fully integrated initially in Network 2. From the 78 stops, 20 could not be included in the network. Because the error message did not give evidence for the nature of the error, the building of the network was quite time consuming. The hints from the official help for frequent problems concerning network building did not apply. Also the compression of the geodatabase and finally generation of a new geodatabase did not help. Finally the network could be built correctly by changing the network settings to "override" for the integration of the point layer. In QGIS the calculated path did not lead along the streets in the beginning. There was no error message or warning. It turned out that the topology and snapping tolerance were set too high.

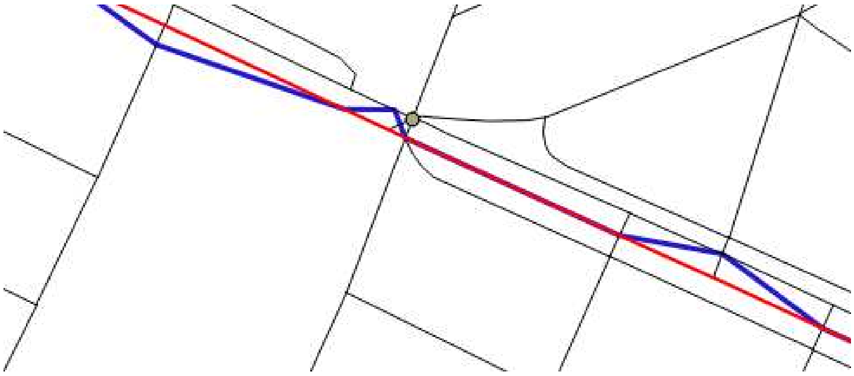


Figure 33 Corrupt routing [blue line] in QGIS due to high topology tolerance

Usability

In the category *usability* QGIS scored 73 and ArcGIS 64 points. QGIS has a better *understandability* and *learnability* because the tool and its features can be used quite intuitively without extensive learning and it includes default settings. The tool is a core plugin which doesn't need further activation and the handling is done in the Road Graph settings and the corresponding panel. In ArcGIS the network analyst is an extension. It is handled with the three elements toolbar, toolbox, and network analyst panel. Due to the big variety of functions, the initial use is not feasible without reading the Help. Although QGIS Road Graph can be used without consulting the Help, there is no German documentation available. Moreover the principles for the calculation of the shortest route are not explained.

Also in the category *operability* QGIS scores slightly higher as the Road Graph is a core plugin and no extensions have to be activated. Anyhow, there were unexpected responses in both programs. For one calculation QGIS did not have time as an output but a combination of letters. Another point could not be routed initially although there was no contradiction with a one-way street. The layers in which the shortest path is stored are just temporary and need to be exported to a new vector layer. In ArcGIS there was a scripting error which required the restart of the program. The stops couldn't be integrated initially, and there were troubles editing the point layer.

Network	ArcGIS	QGIS		ArcGIS	QGIS
Functionality	**79.69**	**82.89**	**Usability**	**63.94**	**71.28**
Suitability	38.71	30.92	Understandability	5.03	6.82
Accuracy	33.00	44.00	Learnability	45.30	49.98
Interoperability	0.00	0.00	Operability	13.61	14.47
Compliance	7.97	7.97			
Reliability	**33.55**	**34.96**	**Efficiency**	**89.87**	**80.37**
Maturity	33.55	34.96	Resources	23.42	25.00
Fault Tolerance	0.00	0.00	Time	66.45	55.37

Table 20 Quality Attributes for Network Analysis in ArcGIS and QGIS

Efficiency

ArcGIS is leading with 90 to 80 points in terms of *efficiency*; in Resources as well as Speed. In ArcGIS the routing points can be digitalized in a point feature layer and afterwards the locations can be added to the network while in QGIS each point needs to be digitalized and exported individually for each of the three network analysis. Furthermore it is possible to build a model and consequently to partly automate the process.

The subcriteria *time* cannot be compared in a profitable way because the two workflows are too different. The calculation of the paths themselves only takes a second, thus the time usage is rather in the setup and storage of data. The speed of these workflows will depend on the user's familiarity with the tools. While in ArcGIS the majority of the time is taken up by building the network including the correct attributes, in QGIS the individual digitalization of the points increases the time usage.

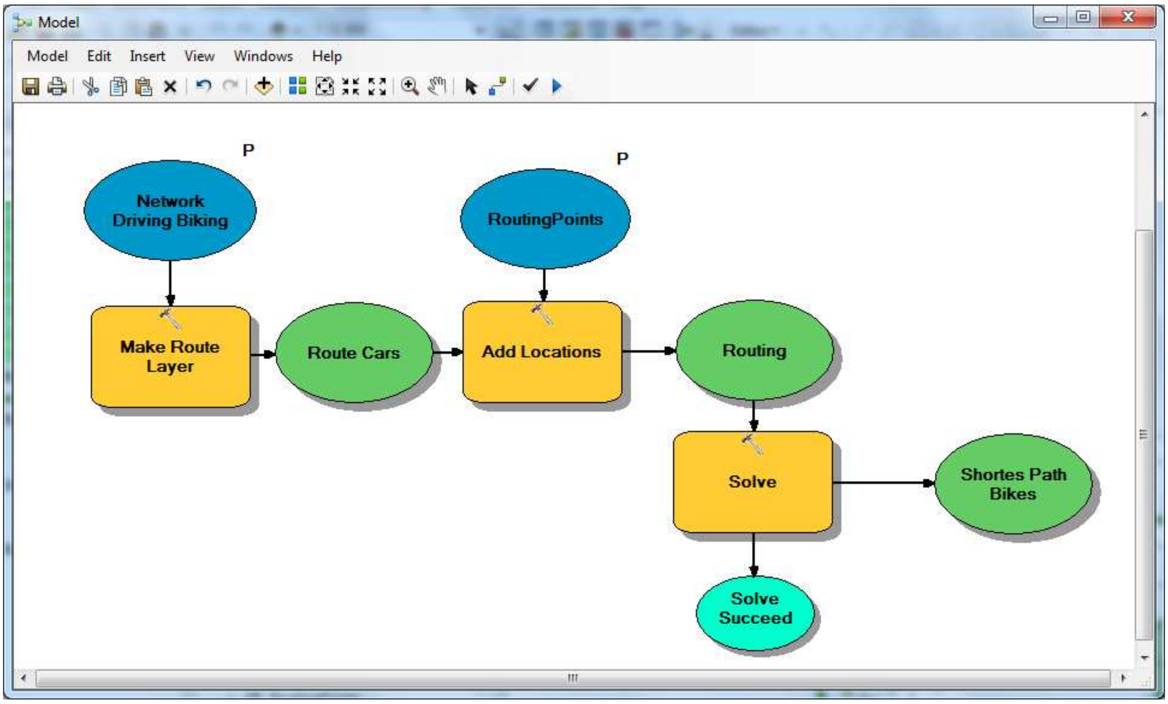


Figure 34 Routing Model for Bikes in ArcGIS

FURTHER POSSIBILITIES

Generally ArcGIS network analyst is way more complex and has several more options for network analysis compared to QGIS which just offers the basic shortest path search. ArcGIS further holds tools for the analysis of routes, closest facility, service area, origin-destination cost matrix, vehicle routing problem, and location-allocation network analyses.

The complexity makes it difficult to use and error-prone. As a result QGIS is more suitable for simple analysis of short routes and GIS beginners, as it doesn't require the building of a network and it can be used intuitively. For complex analysis though, ArcGIS is clearly inevitable, because it offers a range of tools and the incorporation of multiple attributes which QGIS simply does not provide. Additionally it holds the option to automate processes. Furthermore ArcGIS is more suitable for conducting analysis of the same route in different networks as the locations can be added based on a layer file. It is also more efficient when different routes are analyzed in the same territory. Once the network is created it can be analyzed relatively simply.

8.4 Visibility Analysis for Wind Mills

The federal state of Bavaria follows the goal of raising their share of wind energy from 0.6% (2009) to 6-10% until 2021. This requires an installation of more than 1500 new wind mills. Considering the wind conditions in Bavaria, wind mills with heights of 130m or more and power around 2.5 to 3 MW are economic. According to the German Wind Energy Association *Bundesverband Windenergie* 6.2% of Bavaria's area can be used for the production of wind energy already extracting forests and protected areas (CARMEN 2014). The potential areas have been detected in an online wind map with wind speeds and potential energy yields in order to support spatial planning (BAYERISCHES LANDESAMT FÜR UMWELT 2012).

TASK

The aim of this section is to perform a visibility analysis for wind parks. The potential areas where wind parks might be built are extracted from the map on wind potential areas in Bavaria. The areas have wind conditions > 5m/s, >10ha in 130m height and are suitable for the construction of wind parks according to environmental protection and emission regulations (BAYERISCHES LANDESAMT FÜR UMWELT 2012). The visibility analysis will be conducted for a person with eye height 1,70m and wind mills with a height of 130m.

The visibility analysis should include the following criteria:

- Locations: Schwabach (long 10.98474, lat 49.38074), Puschendorf (long 10.8458, lat 49.5360)
- Height of windmill: 130m
- Eye Height of observer: 1.70m
- Minimum Visibility Range: 0m
- Maximum Visibility Range: 50.000m
- Viewed horizontal direction 0° – 360°
- Vertical View Angle: -90° - +90°
- Earth curvature will not be considered because of the small expanse of the area

TOOLS:

- ArcGIS: *Visibility, Viewshed* [Extension: 3D Analyst]
- QGIS: *r.los* [GRASS 6.4], *r.viewshed* [GRASS 7] *Visibility* (Single Point) [SAGA 2.0.8]

ArcGIS *visibility* tool can compute the visible raster surface locations for observer features as well as the observer points which can be seen from each raster surface location.

ArcGIS *viewshed* tool calculates locations on the raster surface which are visible to specific observer features with the help of an input point file. The single cell's visibility is defined through the comparison of the altitude angle to the cell center and the altitude angle to the local horizon. To determine the local horizon the terrain between the observer and the single cell centers are considered. Points lying above the local horizon will be set to visible (ESRI 2014).

QGIS uses the resources of GRASS GIS and SAGA GIS to calculate visibility. GRASS *r.los* performs a line-of-sight raster analysis with the help of coordinates. The cells, visible from a user-specified observer location will receive the value of the vertical angle in which the corresponding cells can be viewed (0 = below observer, 90 = horizontal, 180 = above observer).

GRASS *r.viewshed* generates the viewshed of a point on an elevation raster map with the help of coordinates. *R.los* and *r.viewshed* include the parameters observer elevation, target elevation, maximum distance, earth curvature and refraction coefficient (GRASS DEVELOPMENT TEAM 2014).

SAGA's *visibility* tool calculates the visibility for a single point as SAGA GIS Binary Grid (.sdat) based on a terrain model under the allowance of the target height with the help of a pointer. SAGA's visibility tool cannot be run under QGIS interface.

DATA

Geodata:

EU-DEM-3035: 25m: ***eudem_dem_5deg_n45e010.tif*** [Data Source: EEA 2014]

"*Produced using Copernicus data and information funded by the European Union - EU-DEM layers.*"

- Spatial Reference: GCS_ERTS_1989, units: degree
- Pixel Type/Depth: Floating Point 32 bit, Band 1
- Uncompressed Size: 1,21 GB
- Size (X,Y) 18000 x 18000, Cell Size 0.00037 x 0.00037
- Extend: Top 50, Left 10, Right 15, Bottom 45

Vector Datasets [*for orientation purpose for georeferencing*] roads.shp, railways.shp, buildings.shp, names.shp [Data Source: OSM]

- Geographic Reference System: GCS_WGS_1984, Datum: D_WGS_1984, unit: degree
- Extend: Top: 49,780960 dd, Left: 10,000301 dd, Right: 11,599250 dd, Bottom: 48,868881 dd

Other data:

- Raster file *windparks*.jpeg holding information on Potential Areas for Windparks in Bavaria [Data Source: LfU]

DATA PREPARATION

1. Set up Data Management Structure [ArcGIS: FileGeodatabase, QGIS: SpatiaLite Layer]
2. ***Clip*** DEM, Raster Layer and Vector Layers to Clip Frame with Extend: N 49,559243 dd, W 10,808200 dd, E 11,238406 dd, S 49,307338 dd
3. ***Project*** file to WSG 1984 World Mercator, units=m [EPSG: 3395]
4. ***Resample Raster*** to Cell Size 25m x 25m, Floating Point/ 32bit
5. ***Georeferencing*** of *windpark .jpeg* file with the help of the vector layers

The resulting DHM has the following parameters: Columns (X,Y): 1915, 1719, 12,56MB

WORKFLOW

ArcGIS

1. Creation of ***point feature class*** *WindParks.shp* [EPSG 3395] with potential locations for wind parks according to information of LfU
2. ***Editing*** of new point features [wind parks] including attributes OFFSETA [float] = 1,70m, OFFSETB [integer]= 130m
3. Creation of ***visibility*** maps for a single destination (Schwabach, Puschendorf) based on *WindParks.shp* with

   Option 1: Visibility

   Option 2: Viewshed

QGIS

1. Creation of ***feature class*** *WindParks.shp* [EPSG 3395] with potential locations for wind parks according to information of LfU
2. **Editing** of new point features [wind parks]
3. Option 1: Run ***r.los****,* then **reclassify** *raster* with values view angle -90-+90 = 1, others 0

   Option 2: Install and run ***r.visibility***

   Option 3: Load DHM and WindParks.shp in SAGA GIS 2.0.8 and run ***visibility*** tool and convert file to GeoTIFF

After Option 1 and 2 failed, Option 3 was implemented.

RESULTS

The visibility analysis was performed for two locations Schwabach und Puschendorf. The visibility raster in ArcGIS and QGIS are quite different in both cases. As the height of the observer could not be included in SAGA GIS one would expect, that there are more visible cells in ArcGIS than in QGIS which is not the case. In ArcGIS 72% of the cells were visible while in QGIS it was only 45%.

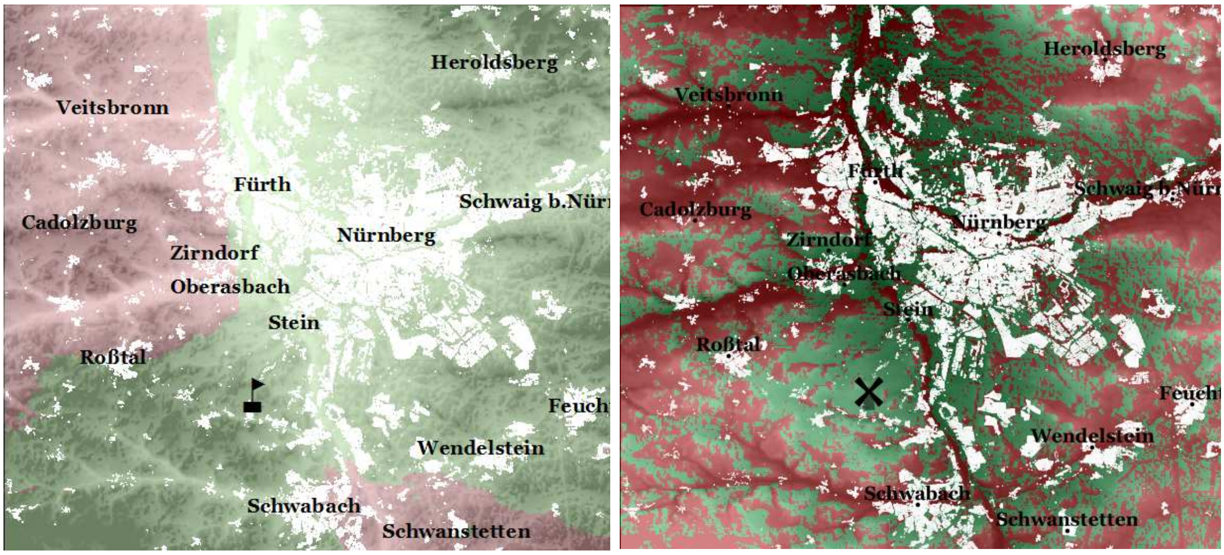


Figure 35 Visibility Raster Map in ArcGIS [left] and QGIS [right] with view axes [green] and without [red] to location wind park Schwabach

In order to determine whether the different visibility raster are a result of the missing observer height the algorithm was performed again in ArcGIS with the observer height 0. The resulting grid looked similar though.

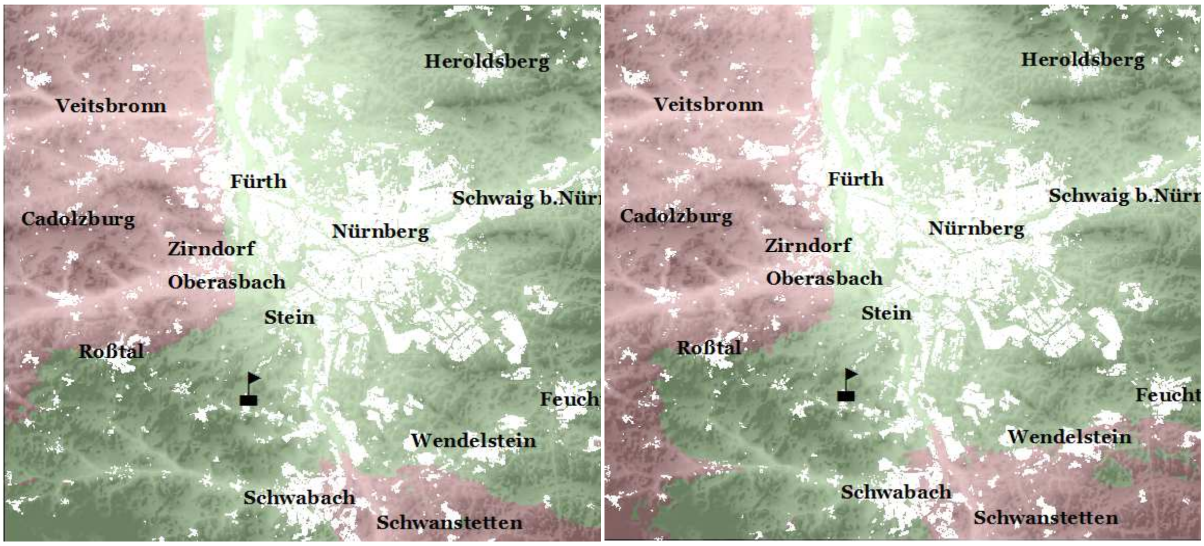


Figure 36 Visibility Map in ArcGIS with [left] and without Offset A

As a result a second set of visibility maps with a second location (Puschendorf) was created. However the results still differ.

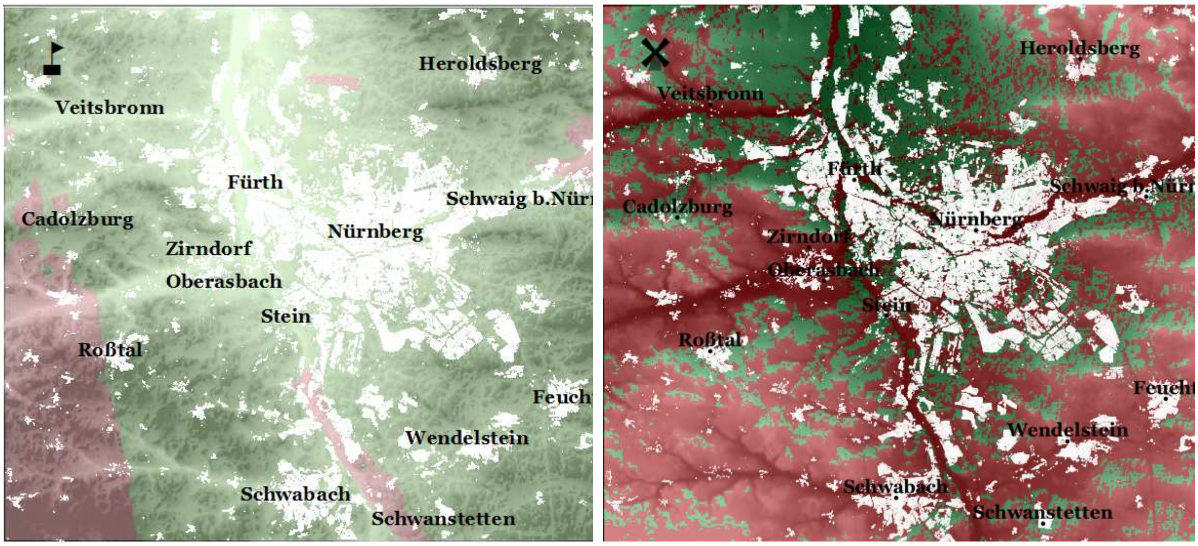
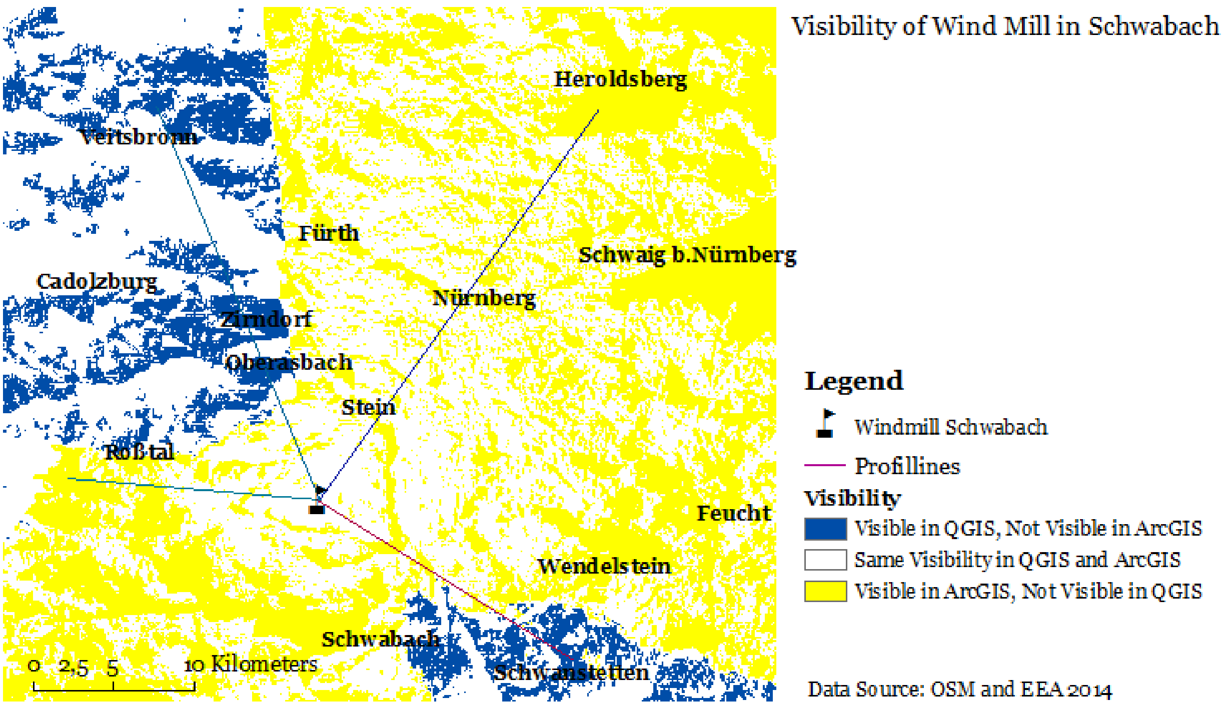


Figure 37 Visibility Map Location Puschendorf

Furthermore ArcGIS *viewshed* tool was used instead of the *visibility* tool, however with the similar result. Also the manual input of the parameters instead of using the attributes in the point feature class did not bring a different result. As a consequence four control profile lines were created to see which program calculated the correct results. ArcGIS visibility raster was set against QGIS visibility raster. The result is a map that shows the areas that have the same visibility in both programs as well as the areas that are only visible in one of the two programs.



Map 1 Visibility of Wind Mill location Schwabach

A new line feature class with four profile lines was created in ArcGIS with two locations that are only visible in ArcGIS (Roßtal & Heroldsberg) and two which can only be seen in QGIS

(Veitsbronn & Schwanstetten). The profiles were created with ArcGIS *Stack Profile* Tool (Extension: 3D Analyst) which generates a table and optional graph with the profile of line features over a terrain surface (Esri 2014). A view axis from the ending point was drawn to visualize whether a 130m high wind mill can be spotted from the location of a 1.7m elevation.

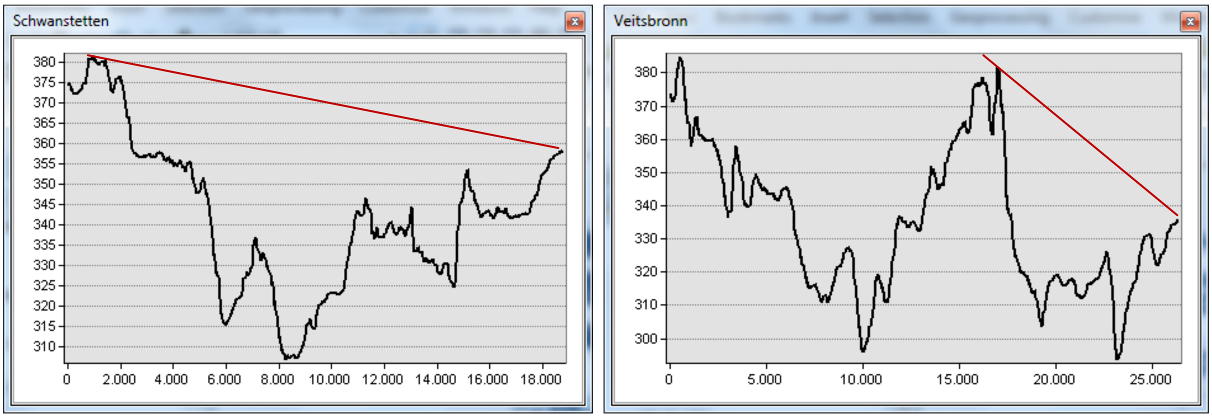


Figure 38 Profiles from Schwanstetten and Veitsbronn to Schwabach

According to the computed visibility maps, the wind mill spot at Schwabach (+130m) can be seen from the locations Schwanstetten, and Veitsbronn in QGIS but not in ArcGIS. As can be seen in the profile, an observer would be able to spot a 130m high wind mill from both locations.

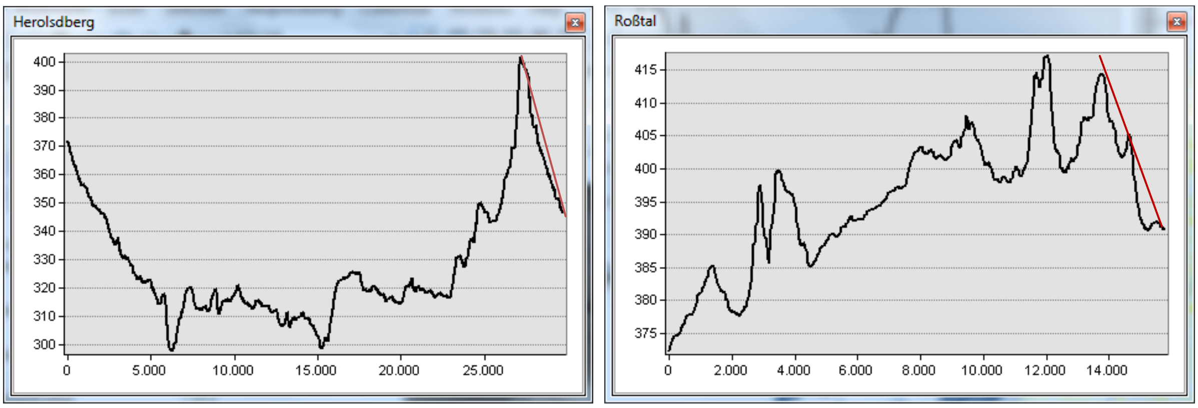


Figure 39 Profiles from Heroldsberg and Roßtal to Schwabach

According to the GIS visibility analysis the locations Heroldsberg and Roßtal were visible in ArcGIS but not in QGIS. From the profile it can be seen that the 130m high Wind Mill cannot be viewed from the locations. In all four examples the result of QGIS visibility map was correct. However, a sample of four locations is too small to determine whether one of the maps is fully correct and the other one is not. The evaluation for *accuracy* only refers to the four examined cases.

Functionality

In ArcGIS the *visibility* tool is part of the 3D Analyst Extension. It can include all required parameters observer height, target height, minimum and maximum distance plus vertical and horizontal view axis.

In QGIS several tools for the calculation of visibility are present but could not be executed successfully. The integrated *r.sol* [GRASS 6.4] tool could not be executed successfully because “lat/long support is not (yet) implemented for this tool” (GRASS GIS 20014). The tool was tested with Geographic Coordinates DHM in WSG1984_World Mercator as well as Cartesian Coordinates with DHM in GCS_ERTS_1989.

Subsequently *r.viewshed* was tried. QGIS 2.6 is only configured to run GRASS 6.4 tools which do not contain the *r.viewshed* tool yet unlike the GRASS 7 version which is not part of the QGIS download package but holds a connection in the processing toolbox. GRASS 7 *beta* which includes *r.viewshed* was downloaded and the path was entered in the QGIS configuration dialog in the processing toolbox according to the instruction. However the tool could not be run with the message that GRASS 7 “is not installed or it is not correctly configured”. As a result, the required tool *r.viewshed* was installed as an add-on in GRASS 6.4 which has a functioning connection. However, this update is not transferred to QGIS despite a restart of both programs.

Finally SAGA’s terrain analysis tool *visibility* (single point) was used. However, the tool is not part of the selection of 228 SAGA algorithms which can be accessed via QGIS interface but has to be applied in SAGA GIS itself. Consequently it was necessary to calculate the layer with the visibility for wind analysis externally and afterwards import it to QGIS. With SAGA’s visibility tool it is only possible to set the height of the observed target, but not of the observer. View range, angle and vertical view axis are not included either which made QGIS rank behind ArcGIS in *suitability* with 26.80 to 41.00 points. QGIS also looses in *compliance* as SAGA GIS transforms the GeoTiff to a SAGA grid format .sgrd and the grid had be converted to a .geotiff again.

Concerning *accuracy* it turned out, that the visibility map that was produced with QGIS/SAGA is more detailed than the one in ArcGIS. All four tested view axes showed an incorrect result in ArcGIS which made it rank behind QGIS with 22 to 44 points.

Visibility	**Weight**	**ArcGIS**	**QGIS**		**Weight**	**ArcGIS**	**QGIS**
Functionality	**100.00**	**73.97**	**74.83**	**Usability**	**100.00**	**94.32**	**10.44**
Suitability	44.00	44.00	26.80	Understandability	7.19	7.19	0.00
Accuracy	44.00	22.00	44.00	Learnability	64.91	64.91	1.84
Interoperability	4.02	0.00	4.02	Operability	27.90	22.21	8.60
Compliance	7.97	7.97	0.00				
Reliability	**100.00**	**55.49**	**55.49**	**Efficiency**	**100.02**	**78.79**	**24.34**
Maturity	87.50	42.99	42.99	Resources	25.00	23.42	20.20
Fault Tolerance	12.50	12.50	12.50	Time	75.02	55.37	4.15

Table 21 Quality Attributes for Visibility/Viewshed in ArcGIS and QGIS

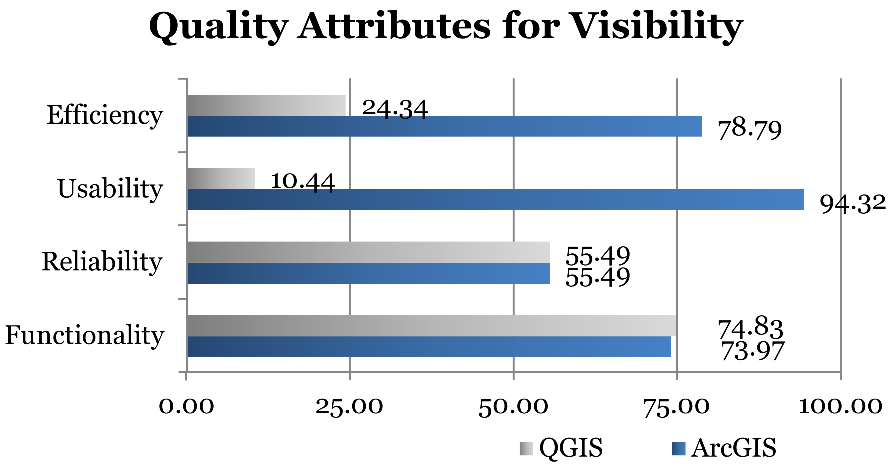


Figure 40 Quality Attributes for Visibility in ArcGIS and QGIS

Usability

Regarding *usability* ArcGIS surpasses QGIS in all categories with 94.32 to 10.44 points. *Understandability* is low as the tool cannot be found in QGIS. Internet research was required to get information on the available tools. In *learnability* QGIS has only 1.84 points compared to ArcGIS with 64.91. No documentation on the tool could be found in the QGIS manual, SAGA GIS homepage, the program itself, or the internet. The tools usage had to be learned by contacting a SAGA GIS user who took GIS training at the Department of Physical Geography in Hamburg where SAGA is developed. The tool's settings or the underlying parameter like the used range, angle, or vertical view axis are not explained. As the algorithm has to be executed in SAGA GIS which has its own interface and logic of handling data, QGIS also ranked lower in *operability* with less than half of ArcGIS points.

Reliability

ArcGIS and QGIS rank equally in *reliability* with 55.49 points as none of the analysis could be implemented in the first try. In ArcGIS the algorithm could not be executed successfully on the first try because the input raster could not be opened. Instead of choosing the data from the drop down list, the file was added by browsing the dataset. In QGIS the tools *r.los* and *r.viewshed* could not be executed as explained before. In SAGA GIS the calculation worked on the first try. However the algorithm to transform the proprietary SAGA grid format .sgrd to a .geotiff failed. The grid had to be converted in QGIS.

Efficiency

ArcGIS is superior in efficiency with 78.79 to 24.34 points. In the category *resources* QGIS has fewer points as it needs SAGA GIS to execute the algorithm.

QGISt is also behind in *speed*. In SAGA GIS the processing time was 00:23 min compared to only 0:07 min in ArcGIS. The transformation to a GeoTIFF requires another 1:18min. Beyond, in QGIS more steps are required to perform the analysis as the file has to be exported an imported again. Moreover it was very time consuming to work with SAGA as it has a different logic concerning data import, layers, and execution of modules than QGIS or ArcGIS and does not have a manual.

FURTHER POSSIBILITIES

ArcGIS has more options to calculate visibility maps. It can include the parameters of the observer and target height, vertical and horizontal view axes, minimum and maximum radius, as well as the refractive coefficient and z value. Furthermore ArcGIS contains tools to calculate variations of visibility. It has the option to process multiple points. Beyond, the number of different observers per raster cell can be determined.

At the moment QGIS does not provide further options for the calculation of visibility maps. The SAGA version 2.1.0 can perform visibility analysis for multiple points. However it is not part of the 2.6 QGIS version. Also GRASS 7 has the *viewshed* tool which can include more parameters which are not part of the current QGIS version.

8.5 Site Location Analysis for Solar Panels

Solar Energy represents a component in the EU's, as well as Germany's future energy mix. Although the federal state of Bavaria has high solar radiation compared to the rest of Germany, the share of electric power generation, generated by solar power, only represent 1.5% (StMWi 2014b) in comparison to the German average of 4.7% (AGENTUR FÜR ERNEUERBARE ENERGIEN 2014). Consequently the potential for expansion of solar parks is quite large in Bavaria. According to the energy concept of the federal state of Bavaria, the share of solar energy should be raised to 16% until 2021 (StMWi 2014b).

TASK

In this analysis, the solar radiation in the area around the city of Nürnberg will be calculated. Additionally, a Site Location Analysis for Solar Panels will be implemented with the aim of finding the best suitable location under the following conditions:

- Type of use: meadow, grass, farmland
- Within a distance of 150m to a negotiable street
- 5m Buffer around streets and railways
- 50m Buffer around waterways
- Minimum width: 20m
- Solar radiation: Areas with radiation higher than the mean of the region for March 31^{st} with azimuth = 32, z factor=1
- Slope <30°

TOOLS

- ArcGIS: *Area solar radiation* [Extension: Spatial Analyst]
- QGIS: *r.sun* [GRASS GIS: Raster]

ArcGIS *Area Solar Radiation* tool is used to calculate the solar radiation across an area from a raster surface. It creates output raster datasets for global, direct, and diffuse radiation in Wh/m², as well as the radiation duration in hours. As input a DHM raster dataset is required. The algorithm incorporates the parameters elevation, slope, aspect, latitude, sky size, z factor, slope, aspect, zenith divisions, azimuth divisions, diffuse model type, diffuse proportion, and transmittivity. The radiation can be calculated for different days, days and hours, for a single day, as well as multiple days (ESRI 2014).

QGIS' *r.sun* algorithm creates the three output raster maps of direct, diffuse, and reflected solar radiation for a specific day and time in Wh/m²/day. Additionally there are the two output raster datasets *Global Radiation* with the sum of all three radiation components and *Insultation Time* for the radiation duration in hours. As input a DHM and raster datasets with terrain aspect and terrain slope are required. The algorithm incorporates the parameters elevation, slope, aspect, latitude, longitude, atmospheric turbidity coefficient, ground albedo coefficient, beam radiation, diffuse radiation, shadowing effect of terrain, and declination value. The radiation can be calculated for different days of a year (GRASS DEVELOPMENT TEAM 2014).

DATA:

EU-DEM-3035: 25m: ***eudem_dem_5deg_n45e010.tif*** [Data Source: EEA 2014] "*Produced using Copernicus data and information funded by the European Union - EU-DEM layers.*"

- Spatial Reference: GCS_ERTS_1989, (EPSG:4258), units: degree
- Pixel Type/Depth: Floating Point 32 bit, Band 1
- Uncompressed Size: 1,21 GB
- Size (X,Y) 18000 x 18000, Cell Size 0.00037 x 0.00037
- Extend: Top 50, Left 10, Right 15, Bottom 45

Vector Layers: ***streets.shp, railways.shp, rivers.shp, landuse.shp, natural.shp*** [Data Source: Open Street Map]

- Geographic Reference System: GCS_WGS_1984, Datum: D_WGS_1984, unit: degree
- Extend: Top: 49,780960 dd, Left: 10,000301 dd, Right: 11,599250 dd, Bottom: 48,868881 dd

DATA PREPARATION:

1. Set up Data Management Structure [ArcGIS: Geodatabase, QGIS: SpatiaLite Layer]
2. Clip DHM and Vector Layers to Clip Frame with Extend: N 49,559243 dd, W 10,808200 dd, E 11,238406 dd, S 49,307338 dd (xMin,yMin 1203163.28,6294756.31 : xMax,yMax 1251053.65,6337753.25)
3. Project and Transform DHM and Vector Layers to WSG 1984 World Mercator, units=m [EPSG: 3395]
4. Resample Raster to Cell Size 10 x 10m, Resampling Method: Nearest Neighbor

The resulting DHM has the following parameters: Columns (X,Y): 4790, 4301, 78,59MB, Cell Size: 10x10m

WORKFLOW

ArcGIS [For Model see Annex]

1. ***Select*** negotiable streets from layer Roads.shp and areas with adequate type of usage (meadow, grass, farmland) from landuse.shp with Query Builder [Data Management Tools]
2. Create ***Buffer*** around Roads.shp, Waterways.shp and Railways.shp [Analysis Tools]
3. Calculate raster with ***Slope*** from DHM, transform ***raster to polygon*** and ***Select*** Features with Slope Degree >30° (Output: Slope.shp) [Data Management Tools]
4. ***Union*** negative Areas, ***Intersect*** Positive Areas and ***Erase*** Negative Areas from Positive Areas (Output: PotentialAreas.shp) [Analysis Tools]

5. ***Dissolve*** Features and apply ***Mulitpart to Singlepart*** [Data Management Tools]
6. ***Intersect*** PotentialAreas.shp with Slope.shp and apply ***Mulitpart to Singlepart*** (Output: SolarPark.shp)
7. From DHM calculate ***Area Solar Radiation*** for Day 90 (March, 31st) [Spatial Analyst]
8. ***Reclassify*** the Radiation raster (Direct Radiation) in the way that cells with a value for solar radiation > 4037 KWh have value 1 and others 0 [Spatial Analyst], convert ***raster to polygon*** [Conversion Tools] and ***select*** features with value=1 (Output: HighRadiation.shp)
9. ***Intersect*** HighRadiation.shp with SolarPark.shp (Output: HighRadiation.shp)
10. Create negative ***Buffer*** **(-10m)** to identify areas with a width <20m and afterwards apply positive ***Buffer*** **(10m)** to get the original shape back [Analysis Tools]; apply ***Mulitpart to Singlepart*** (Output: SolarParkFinal.shp)
11. Create Field for ID and extract the solar radiation for areas in SolarparkID with ***Zonal Statistics as Table*** [Spatial Analyst]
12. ***Join*** resultant Table to SolarParkFinal.shp

QGIS [No Model]

1. ***Select*** negotiable streets ***by attributes*** from layer Roads.shp (Query: type in ('living_street' , 'motorway' , 'motorway_link' , 'primary' , 'primary_link' , 'residential' , 'road' , 'secondary' , 'secondary_link' , 'tertiary' , 'tertiary_link' , 'turning_circle') and areas with adequate type of use (meadow, grass, farmland) from landuse.shp with query builder [Vector Selection Tools]
2. Create ***fixed distance buffer*** around Roads.shp, Waterways.shp and Railways.shp [Vector geometry tools]
3. Create slope raster layer from DHM with ***Slope*** and ***polygonize*** [GDAL/OGR Conversion] it; then create new layer with slope<30° using ***extract by attribute*** [Vector Selection Tools] 15:33min
4. Apply ***Multipart to Singlepart*** [Vector geometry tools] and ***Dissolve*** Areas [SAGA Shapes - Polygons]
5. ***Union*** negative Areas, ***Intersect*** Positive Areas and Create the ***Difference*** between Negative Areas from Positive Areas (Output: PotentialAreas.shp) [Vector overlay tools]
6. ***Intersect*** [Vector overlay tools] Potential Areas with Areas with slope <30° (Output: PotentialAreasSlope)
7. From DHM create raster layer with ***Aspect*** and calculate ***r.sun*** for Day 90 [GRASS: Raster]
8. Create. txt File with reclassification rules and apply ***r.reclass*** [GRASS: Raster] in the way that cells with a value for solar radiation > 4037 KWh have value 1 and others 0
9. Create a Vector Layer with ***polygonize*** from reclassified raster [GDAL/OGR Conversion]

10. ***Select*** field with value = 1 and ***intersect*** areas with Potential Areas.shp for Solar Park [Vector overlay tools]
11. Create ***fixed distance buffer (-10m & 10m)*** with option ***dissolve*** to extract areas with a minimum width of 20m and afterwards apply ***multipart to singlepart***
12. Create a vector layer including the values for solar radiation with ***Zonal Statistics*** [Raster Tools]

RESULTS

In both programs the solar radiation maps could not be calculated from the projected raster datasets but had to be generated from the original file and projected afterwards.

Both programs computed a similar mean daily radiation durance with 12.1 (ArcGIS) respectively 11.7 hours (QGIS). However, the raster output for radiation in ArcGIS and QGIS showed differences in the values. While ArcGIS computes a mean global radiation of 5721 Wh/m², QGIS computes 3974 Wh/m² which represents a 30.5% difference. This is mainly due to the fact, that ArcGIS radiation algorithm suggests a diffuse radiation which is twice as high as the one of QGIS and the global radiation is the sum of direct and diffuse radiation. The values for direct radiation on the other hand are quite similar. With values of 4037 Wh/m² in ArcGIS and 3976Wh/m² in QGIS, the difference in direct radiation is only 1.6%. As solar panels mainly use direct radiation, the raster for direct radiation was chosen for further analysis.

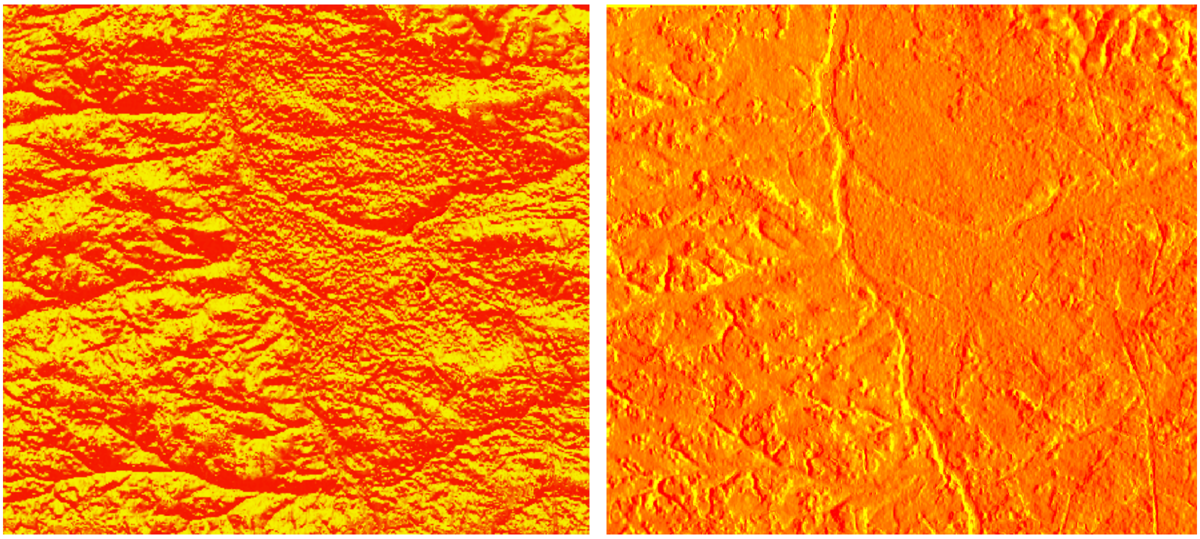


Figure 41 Direct Radiation in ArcGIS [left] and QGIS [right]

Output Dataset	Value	ArcGIS	QGIS	Difference
Global Radiation $[Wh/m^2]$	Min	0	1961	
	Max	11607	5235	
	Mean	5721	3974	30,5%[4]
Diffuse Radiation $[Wh/m^2]$	Min	0	705	
	Max	3687	1081	
	Mean	1684	909	46,0%
Direct Radiation $[Wh/m^2]$	Min	0	1967	
	Max	8073	5235	
	Mean	4037	3974	1,6%
Reflected Radiation $[Wh/m^2]$	Min	-	0	
	Max	-	290	
	Mean	-	1	
Radiation Duration [h]	Min	0	6	
	Max	12.53	12	
	Mean	12.10	11.7	3,3%

Table 22 Comparison of Radiation Output in ArcGIS [left] and QGIS [right]

The values also showed differences in the minimum and maximum values. ArcGIS showed more differentiated values for all raster datasets. This is visible in the raster's histograms.

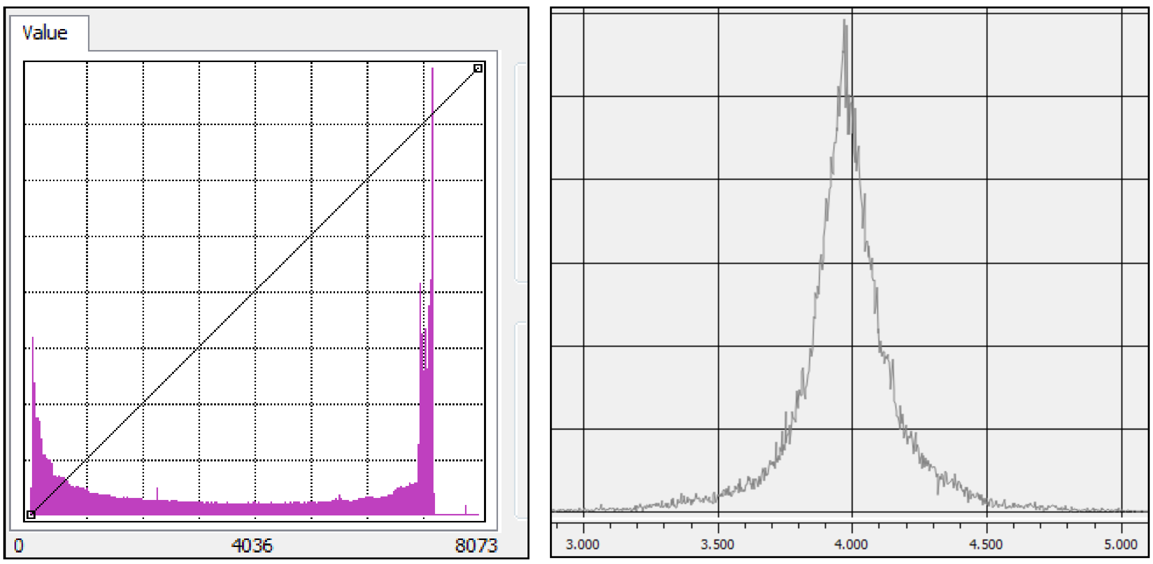


Figure 42 Comparison of Histograms for Direct Radiation in ArcGIS [left] and QGIS [right]

While ArcGIS computes a big proportion of values around the minimum and the maximum, QGIS computes the maximum around the mean which can also be seen in the visualization of the direct radiation.

This can be explained with the fact, that QGIS compresses the raster way more during the calculation process. ArcGIS keeps the original number of cells of 18000 x 18000 cells while QGIS compresses the raster during the calculation process of slope, aspect, and solar radiation to a raster with 1152 x 909 cells.

[4] All percentages in relation to ArcGIS as absolute value

For the site location search, QGIS suggests 539 and ArcGIS 564 areas which fulfill the requirements. Despite the differences in the radiation maps, both programs had the same output in the solar park search in terms of the largest suitable area. The area with the highest radiation is however different which can be explained with the coarse raster of QGIS which leads to more generalization and consequently lower values. In ArcGIS the areas showed solar radiation values between 4051 and 7247 Wh/m² with a mean of 6403Wh/m². In QIS the values vary between 3074 and 5985 Wh/m². The figure below holds an explanation for the smaller number of suitable locations in QGIS. The areas are more generalized for instance when the buffers were subtracted and thus areas were removed during the geoprocessing operations.

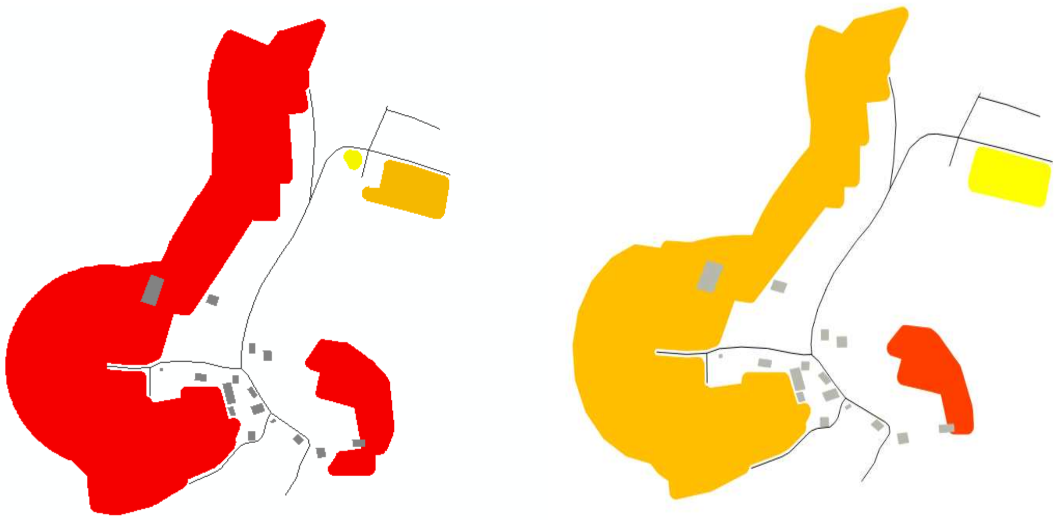


Figure 43 Larges Suitable Location in ArcGIS [left] and QGIS [right]

Functionality

ArcGIS scores slightly lower in functionality than QGIS. Concerning *accuracy*, both programs deliver a correct result. This result shows more differentiated values in ArcGIS though. In this way the locations with the highest radiations can be identified better. When it comes to *suitability*, QGIS provides some more options. This applies to the amount of topology parameters. For instance apart from the height values of the DHM, QGIS allows inputting extra aspect and slope raster datasets, while ArcGIS calculates both from the DHM. In this way QGIS can include information for the orientation of solar panels. However, ArcGIS has more settings for the calculated time span of the radiation. Apart from the calculation of radiation for specific days, hours and intervals of a day which can be done in QGIS, ArcGIS can further calculate the radiation over several days or even a year with monthly intervals. But on the other hand, GRASS GIS algorithm additionally determines the reflected radiation.

In terms of *compliance* the two programs rank similarly as they work with Geotiff files while QGIS wins for *interoperability* since it can use the resources of GRASS GIS.

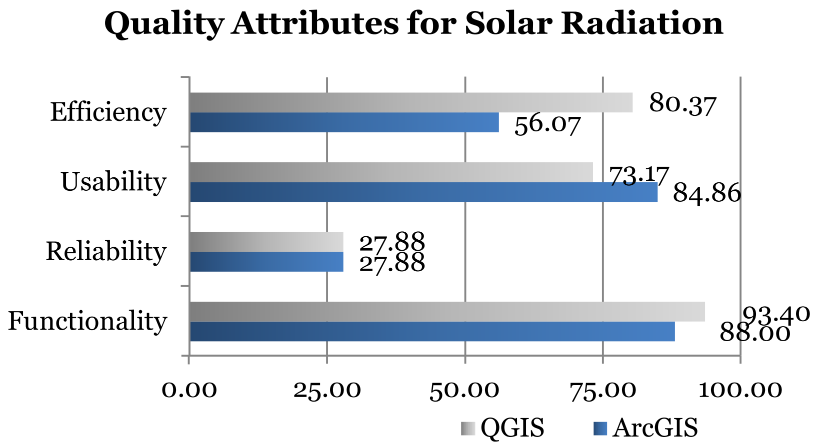


Figure 44 Quality Attributes for Solar Radiation

	Weight	ArcGIS	QGIS		Weight	ArcGIS	QGIS
Functionality	**100.0**	**88.0**	**93.4**	**Usability**	**100.0**	**84.9**	**73.2**
Suitability	44.0	36.0	37.4	Understandability	7.2	6.8	6.8
Accuracy	44.0	44.0	44.0	Learnability	64.9	59.4	48.7
Interoperability	4.0	0.0	4.0	Operability	27.9	18.6	17.7
Compliance	8.0	8.0	8.0				
Reliability	**100.0**	**27.9**	**27.9**	**Efficiency**	**100.0**	**56.1**	**80.4**
Maturity	87.5	27.9	27.9	Resources	25.0	23.4	25.0
Fault Tolerance	12.5	0.0	0.0	Time	75.0	32.6	55.4

Table 23 Quality Attributes for Site Location Analysis

Efficiency

QGIS leads in *efficiency* mainly because of speed as it could perform the radiation algorithm a lot faster than ArcGIS. The calculation of the solar radiation took 20:02 minutes in QGIS while the algorithm was performed 5:07:32 hours in ArcGIS. The tool was applied 3 times with different settings. The tool always ran more than 5 hours. However it has to be considered that ArcGIS calculates with a taller file.

A benefit in ArcGIS is the option to build a model which can be used for further analysis. QGIS graphical modeler was not appropriate to build a model as there is no option to name the outputs which makes the construction confusing.

When comparing the *resources* both rank equal, apart from the fact, that in ArcGIS the extensions need to be activated first.

Reliability

Both programs ranked low for the quality attribute *reliability* as several obstacles had to be overcome during the analysis. None of the radiation algorithms could be performed on the first try.

In ArcGIS the solar radiation tool was run twice without a result for the projected raster dataset so that the calculation process had to be stopped at some point. The first time it ran for 7.5 hours, the second time for 12 hours. As a result the algorithm was run on the original file. ArcGIS caused an error in calculating horizon and radiation and failed to execute the function. After several scripting errors a restart in ArcGIS was necessary.

When slope and aspect were calculated in QGIS from the projected file, the resultant raster contained several *Null* values which also influence the accuracy of the solar radiation map. The algorithms were run with QGIS internal slope and raster tools, as well as GRASS *r.slope.aspect* tool which showed a similar result.

When slope and aspect were calculated from the unprojected raster the results did not contain *Null* values. When the algorithm was first run in QGIS, the program stated that the output layers could not be opened. After a restart the algorithm could be performed completely. The solar radiation raster which was then created from the projected raster and corresponding slope and aspect showed similar values as the one created from the unprojected raster. The raster had a mean of 3976 Wh/m² compared to 3974 Wh/m² for direct radiation. Consequently the raster created from the unprojected raster was used because it did not contain *Null* Values and will bring a better result for the further location analysis.

Usability

ArcGIS has the higher usability concerning the solar park analysis. It has more points in *learnability* as well as *operability,* while in *understandability* both programs rank equally. ArcGIS has documentation in German and each parameter is explained in the tool settings, while in QGIS they have to be looked up in the tool description. The major constraint for usability in both programs is the nature of the error messages. Not all of them hold information for the nature of the error which makes it difficult and time consuming to find a solution. Additionally, both programs contained unexpected responses. Another constraint in QGIS is the issue that the reclassification of the slope raster dataset did not work out in the first place. The reclassification rules have to be written in an external .txt file in order to use the GRASS tool *r.reclass*. The syntax had to be adapted until the result was correct which could be seen in the histogram.

FURTHER POSSIBILITIES

ArcGIS has further options to calculate radiation. ArcGIS *Points Solar Radiation* tool is used to calculate the amount of radiant energy for a given location. Locations can be stored as point features or as x,y coordinates in a location table. Furthermore *Solar Radiation Graphics tool* can generate visualizations of the visible sky (viewshed map), the position of the sun in the sky over a time span (sunmap), as well as the sky areas that determine the value of solar radiation (skymap) (ArGIS Resources 2014).

GRASS GIS *r.sunmask* computes cast shadow areas given a specific sun position and elevation raster map. Additionally SAGA GIS has a *sky view factor* tool that creates a raster dataset of the visible sky. So far there is no equivalent to ArcGIS Point Solar Radiation tool and the ArcGIS option to compute solar radiation over the year.

8.6 Findings for Georeferencing and Editing

#Georeferencing

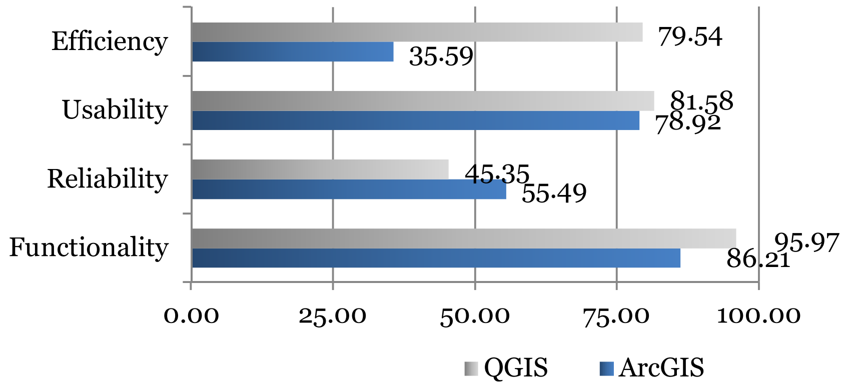


Figure 45 Quality Attributes for Georeferencing

ArcGIS and QGIS have comparable *functionality* for georeferencing raster datasets including georeferencing based on geographical coordinates or a georeferenced dataset. Both provide the options to save and delete Ground Control Points. Finally, ArcGIS and QGIS respectively hold several options for resampling methods and transformation types. However, the handling shows fundamental differences. The *usability* in QGIS is easier due the fact that the raster dataset is not rotated and scaled during the georeferencing process but stays rectangular and horizontal. Furthermore it is possible to view and operate the georeferencing window and map view simultaneously and ground control points can be adapted instead of deleted and recreated. The distortion and rotation of the raster in ArcGIS makes the georeferencing process slow and prone to failure. This results in the process taking twice as long in ArcGIS compared to QGIS. The downside of georeferencing with QGIS is the fact, that the raster was not updated in the first place due to syntax infringement in the output file. As there is no visual feedback for active calculation process, the failure cannot be assessed instantly.

	Weight	ArcGIS	QGIS		Weight	ArcGIS	QGIS
Functionality	**100.00**	**86.21**	**95.97**	**Usability**	**100.00**	**78.92**	**81.58**
Suitability	44.00	34.24	44.00	Understandability	7.19	6.82	6.82
Accuracy	44.00	44.00	44.00	Learnability	64.91	48.66	48.66
Interoperability	4.02	0.00	0.00	Operability	27.90	23.44	26.10
Compliance	7.97	7.97	7.97				
Reliability	**100.00**	**55.49**	**45.35**	**Efficiency**	**100.02**	**35.59**	**79.54**
Maturity	87.50	42.99	45.35	Resources	25.00	22.60	24.17
Fault Tolerance	12.50	12.50	0.00	Time	75.02	13.00	55.37

Table 24 Quality Attributes for Georeferencing

#Editing

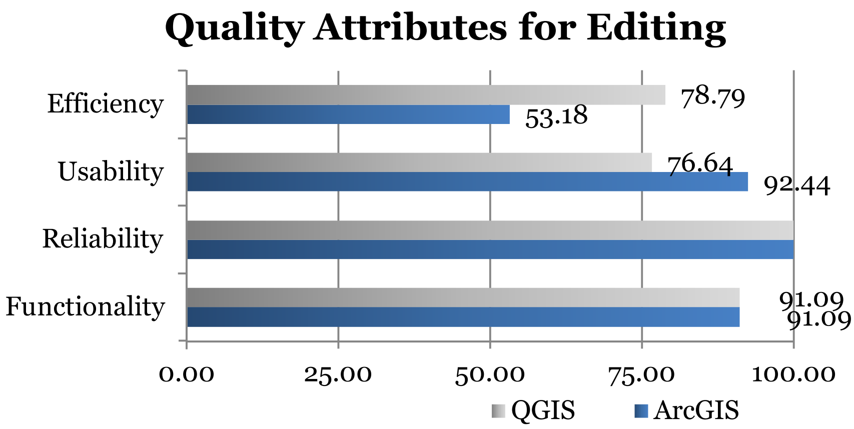


Figure 46 Quality Attributes for Editing

ArcGIS and QGIS provide the options to edit features in existing layers and creating new layers and features. When new layers are being digitalized, first a new shapefile layer needs to be created in both software. In order to use the *Topology tool*, layers have to be arranged in a geodatabase in ArcGIS. In QGIS the digitalizing of new features can be started straight away with default symbology while ArcGIS requires the creation of *feature templates* with the visualization of features first.

	Weight	ArcGIS	QGIS		Weight	ArcGIS	QGIS
Functionality	**100.00**	**91.09**	**91.09**	**Usability**	**100.00**	**92.44**	**76.64**
Suitability	44.00	39.11	39.11	Understandability	7.19	6.82	6.82
Accuracy	44.00	44.00	44.00	Learnability	64.91	63.60	52.62
Interoperability	4.02	0.00	0.00	Operability	27.90	22.02	17.20
Compliance	7.97	7.97	7.97				
Reliability	**100.00**	**100.00**	**100.00**	**Efficiency**	**100.02**	**53.18**	**78.79**
Maturity	87.50	87.50	87.50	Resources	25.00	23.42	23.42
Fault Tolerance	12.50	12.50	12.50	Time	75.02	29.76	55.37

Table 25 Quality Attributes for Editing

The *functionality* for editing is comparable. Features that are available in both programs are *add feature*, *move feature*, *delete*, *edit vertices*, *copy and paste features*, *rotate features*, *reshape*, as well as *split and merge Tool*. Additionally they both have a *tracing tool topology checker* for quality assurance. In addition ArcGIS has a selection of advanced editing tools which facilitate specific editing task like for instance *Fillet Tool* for the creation of a tangent curve or *Line Intersection* to split features on intersections.

Nevertheless the editing process for simple features is more *efficient* with QGIS. It holds the option to enter a newly digitalized feature's attribute instantly in a pop-up window without using the attribute table window. Another benefit of editing in QGIS compared to ArcGIS is the workflow for editing vertices. While in ArcGIS the tools for inserting vertices and moving vertices have to be switched, in QGIS both functions can be implemented with the same tool by double clicking for new vertices and a single click for moving vertices. Another useful feature in QGIS is the visibility of being in the digitalizing mode in the map viewer as certain GIS processes cannot be implemented in this status. However ArcGIS has certain advantages in *usability*. A disadvantage of QGIS *operability* compared to ArcGIS is the fact that the feature ID for new features is not given by default but must be added manually. There will be no warning in case of typing an identical feature ID. Another constraint is the lack of *undo* functionality while drawing a polygon. Moreover, ArcGIS has an advantage in *learnability* because it has integrated help windows with hover effect that explain the tools.

Generally, the different handling results in the fact that digitalizing was faster in the test with QGIS than with ArcGIS. The *reliability* of both software was given, but none of them showed defects.

9 Discussion of the Findings

In this section the results of the Discourse Analysis, Expert Interviews and Test Analysis will be discussed.

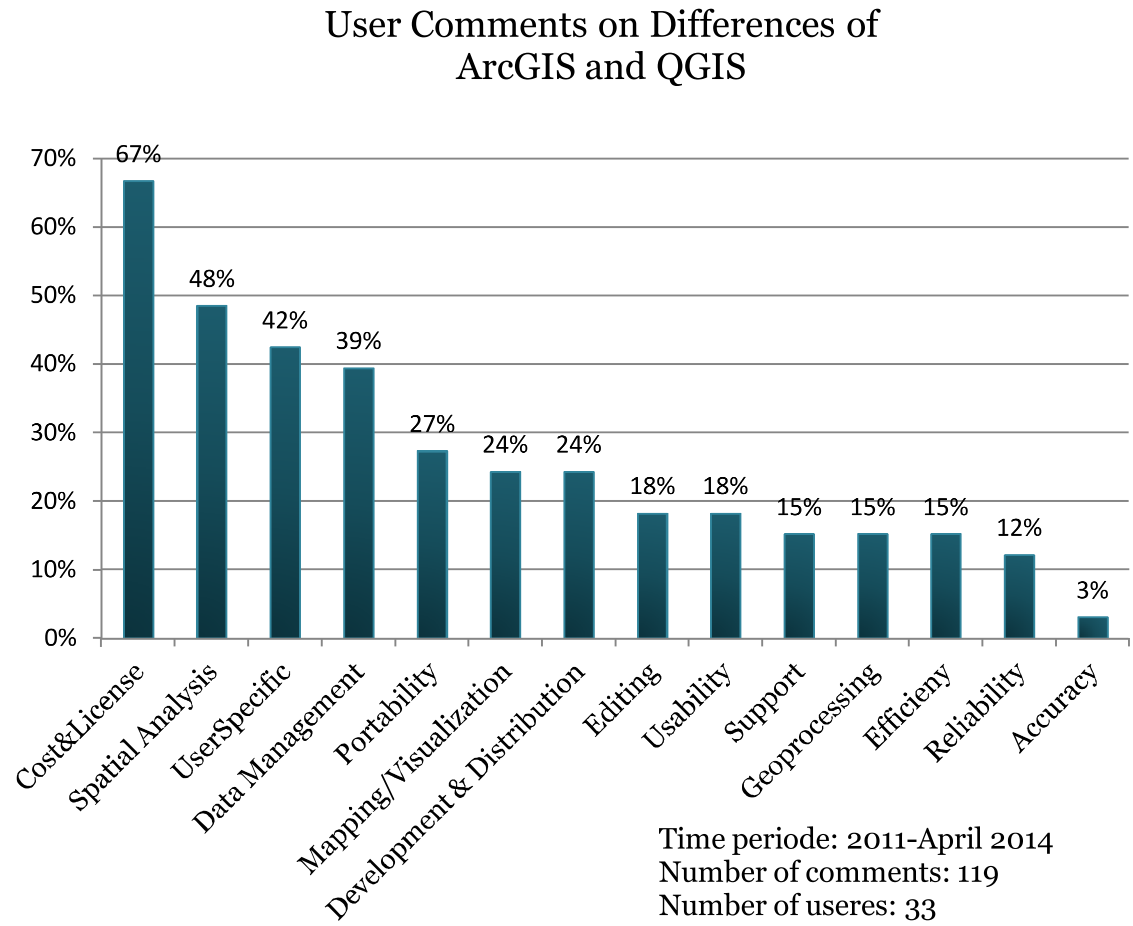


Figure 47 Results of Discourse Analysis

9.1 Parameters and Personal Preference

The Discourse Analysis revealed which characteristics GIS users considered important when they were asked about the differences of ArcGIS and QGIS in form of an open question. The most important factor, which was named by 67%, was differences in Cost & License, followed by Spatial Analysis Tools which was stated by half of the users. 42% of users emphasized that the answer, which software was more appropriate would depend upon the specific task and user or company which strongly supports the idea of this thesis.

Personal Preference

"The answer depends on whether you are willing to get dirty, have a limited budget, love seeing what's going on behind the hood and your understanding of GIS concepts... But at the end of the day, you are able to accomplish your tasks whichever way you go ..." (**David Ndegwa Kuria** - Dedan Kimathi University of Technology 2013)

42% of users stated that the answer, which software was more appropriate would depend upon the specific task and user. Some users state that the software itself is not important but rather the geodata and the sort of task that has been accomplished. The software itself is just a tool and not the target. Another aspect which was mentioned several times is the context in which the software is used. Some users suggested that enterprise teams should rather choose commercial GIS software while private users should go with OS. FINK neglects this view. *"You can't say that in general, especially large enterprises have the necessary manpower, skills and endurance to adapt open source software to their need [...] I think it would also fit to an enterprises own image to contribute to an open project, it might be a question of philosophy [...]" (FINK 2014).* In fact QGIS has several sponsoring organizations worldwide.

Other comments underlined that the software choice depends on the personal preference as well as the knowledge and skills of the user. In this context it is mentioned that any GIS software will not be sufficient anymore at some point for advanced users, as they will have to program their own tools. In this context a study on the relation between technology and human resources can be named. The Cambridge based high tech entrepreneur HAUSER claims that humans are more important than technology which has been proven in comparisons where a highly qualified team with inferior technology archives better results than a less qualified team with superior software (HAUSER 2014).

#Costs & Licenses

In the discourse analysis the point of *costs & licenses* was mentioned most frequently by 67% of the users. It is mentioned so often because QGIS is free and it is a strong criterion for institutions and companies with a small budget, and for collaborations with third world countries. Furthermore *"...a private user cannot afford an ArcGIS license; that's just incredibly expensive and also small businesses or joint offices might not be able to afford the license either"* (FINK 2014). Further it is argued, that the availability of several GIS versions in an office can reduce waiting times. Other users comment that the license protection software of ArcGIS "*often brings problems in a multiuser environment"* (Comment 23). Another user stated that most ArcGIS problems were related to the copy protection (Comment 12). Finally it was suggested, that while there is only one QGIS for Desktop version, it has to be considered, that there are different versions with different performances and costs for ArcGIS for Desktop (Comment 9 & 30). Users complained that certain tools, which they consider to be standard tools like the geoprocessing tool *Erase* are not even part of the basic ArcGIS version but the advanced one while there is the free *Difference* tool in QGIS. Consequently some users state that ArcGIS is simply "overpriced" and that it does not make sense for a company which only uses GIS software sporadic for simple data visualization and basic analysis to purchase a costly license.

However, there are also users stating that "*business is not always about saving money, it is often about reducing financial RISK*" (Comment 31). Using proprietary software instead of OS software gives the company a certain warranty.

#Development and Distribution

In the discourse analysis 24% of the users named the software's development and distribution as a difference. The market share of the respective software can be a criterion for its use by a company. In the discourse analysis it was mentioned that there are more trained

ArcGIS professionals on the market than for QGIS. This is a point that companies and institutions have to take into account, as it will be harder to find qualified employees which don't need extra training to fulfill their tasks. Another point was the importance of using the same GIS software as business partners or other departments due to the necessity of data exchange. Moreover, there were users stating that open source was not yet fully accepted in academia. This might be another constraint of implementing QGIS.

On the other hand, there were also statements making clear, that open source solutions were "getting stronger" in terms of their features and their popularity. This could also be seen in QGIS release cycle as well the analysis of Google trends. QGIS is developing very fast in terms of its features which can be underpinned with the statements of QGIS experts.

"*QGIS really improved over the last couple of years maybe three/four years, at a really impressive speed [...] and it's really worth installing the developer version because there is already such a feature improvement [...] QGIS has such a short release cycle you would have a new version every three to fourth month [...] I think many people are not aware, many people in professional businesses…"* (FINK 2014).

The US American GIS software consultant DUGGAN supports this view: "*Over the last couple of years open source software has done a ninja attack, the quality of the FOSS GIS software now is nothing less than remarkable*" (DUGGAN 2013). Moreover he makes clear that the high costs of ArcGIS are not in relation to its performance anymore as FOSS GIS provide the same functions for free. As ArcGIS represents the leading GIS software for a long time, it hasn't "*really moved with the times, the software has become clunky and sluggish in comparison to the FOSS*" (DUGGAN 2014).

The rise of OS software has also affected ArcGIS. ESRI launched an initiative to integrate OS elements in their products and consequently to make samples and products available to users for free (MIRCROSOFT 2014a). ESRI is on GitHub since February 2013 and is also promoting this step on their homepage: "*We're excited about helping developers build and share software. Browse our open source code and get started with our powerful ArcGIS platform today*" (ESRI 2014).

Finally it can be stated that the growing popularity of QGIS does not necessarily implicate a market share loss for *Esri* products. In fact the market for GIS products has generally been growing in the last decade. This is supported by the Google trends analysis that showed the highest scores for ArcGIS searches in Bolivia, China, Mongolia, Ecuador, and Nicaragua.

 # Support

In the discourse analysis comments concerning "Support" were made by 15% of the users. It was suggested that companies are better advised working with ArcGIS when they need frequent support as "*Esri has a well established knowledge base, peer support forum, and technical support system*" (Comment 30).

None of the users brought up that there is also commercial support for QGIS which could mean that it is not yet general knowledge. Rather users pointed to QGIS peer support via the *gis.stackexchange.com* site (Comment 30) and underlined that "*FOSS has a great community too, if I find that I DO have an issue (with the base system, not the plug-ins), there is usually an answer within 48hrs"* (Comment 31).

9.2 Functionality

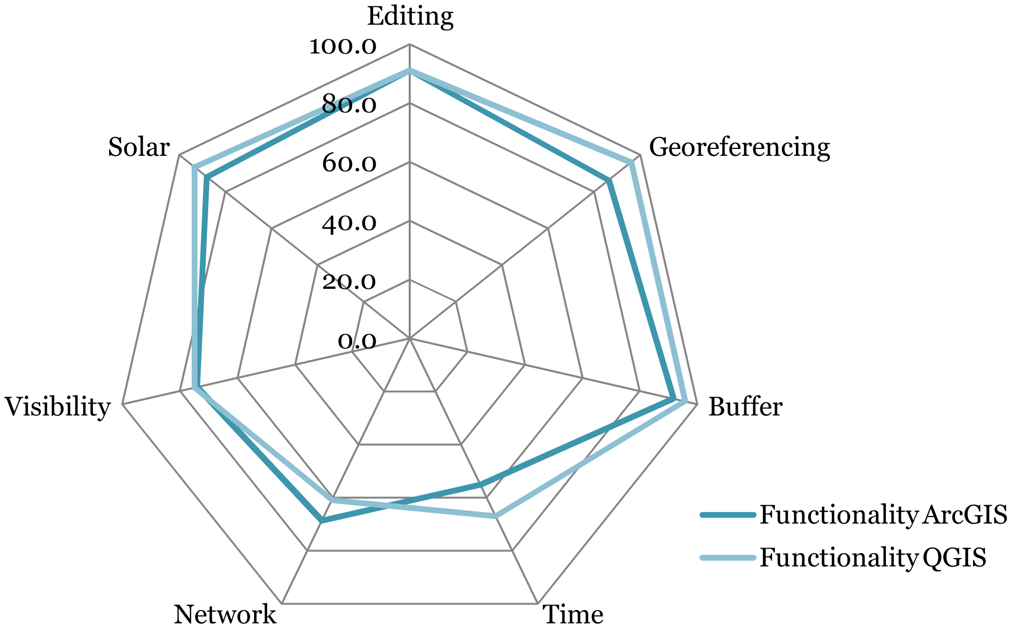


Figure 48 Comparison of Functionality for different features

Concerning ***suitability*** ArcGIS provides more 'out-of-the-box' functionality than QGIS. The conducted analyses were chosen in a manner so that they can be executed with both programs. The section on further possibilities in each analysis shows the exceeding functionalities in the fields which are generally won by ArcGIS. An advantage was detected favoring QGIS in terms of selected tools. This was the case for the solar radiation tool which has sophisticated settings in GRASS GIS. Also SAGA's Buffer which can create rings based on a scaled value can be named, as well as the integration of several feature datasets in QGIS time manager.

A detailed evaluation was also done for the cartographic functionality. It showed two things that can be transferred to the general functionality. First, "*Commercial programs are among the best because they have been developed for a long time, and thus have the chance to meet the requirements of expert cartographic outputs*" (DOBEŠOVÁ 2013). The second aspect though is the fast growth of functionality in QGIS. When CartoEvaluation Method was used in 2009 on *Quantum GIS 1.0.2* "Kore" (January 2009-May 2009) it scored 43.85 points which represents an improvement of 32.17 points to the current 76.08 points in 5 years. While ArcGIS basically stagnated with an improvement of 1.31 since version *ArcMap 9.3* where it scored 82.25 points.

When looking at the brought functionality there are areas which QGIS does not cover at all, like for instance 3D data, animations, or advanced network analysis. Network analyses represent an important part of spatial planning. In QGIS programming skills are needed to implement other analysis than the Shortest Path.

A user stated in February 2012 "*QGIS is really coming on and has almost reached a point where I think I could live completely without ArcGIS…*" but further states "*…if I add a bit of scripting in GDAL/OGR plus PostGIS etc.*" (C9)

An aspect that needs to be considered when discussing functionality is the fact that ArcGIS for Desktop has three variations Basic, Standard, and Advanced which bring different functionality and can further be adapted with extensions. Here the users have to consider carefully what they need. When a basic tool is needed the whole package has to be bought. As an example the Geoprocessing *Erase* tool can be named. It is not part of the core analysis like *Clip, Buffer, Intersect, Select*, or *Spatial Join* but only available in the advanced version.

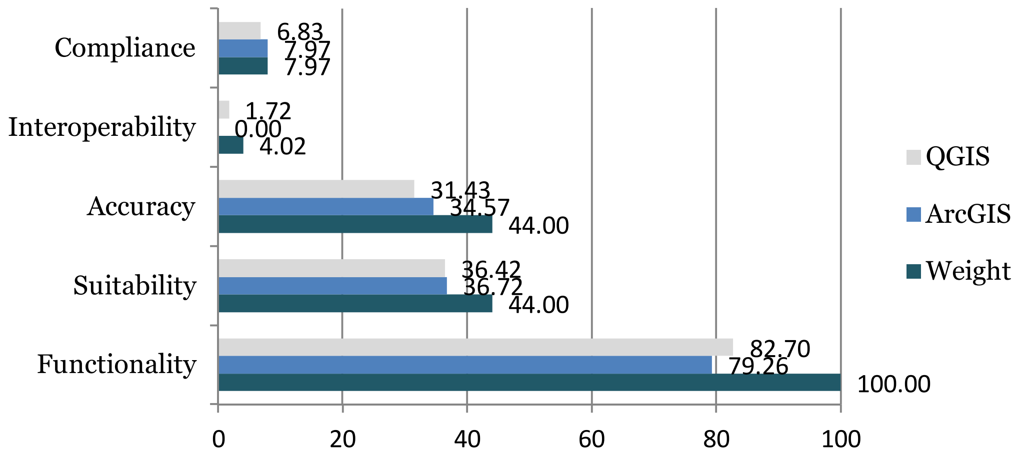


Figure 49 Quality Attributes for functionality

In terms of ***accuracy*** both programs delivered good results and are about even, although it has to be mentioned, that the correctness of the outputs could only be determined by the consistency of the data.

Concerning the quality attribute ***interoperability*** the two programs do show significant differences with QGIS taking the lead. In the discourse analysis differences in spatial analysis ranked number two and was named by half (49%) of the users. Most of them mentioned that ArcGIS has more out-of-the-box analytic capabilities with the concept of the toolbox (C4, C16, C20, C30). Users stated that ArcGIS has generally more tools and is "*powerful for complex analysis"* (C20). As special emphasize was put on ArcGIS Raster Analysis tools compared to QGIS limited possibilities (Comments 6 & 9).

Indeed QGIS has limited internal algorithms and thus uses the "*processing toolbox which is trying to be an equivalent but which lives rather from the bindings to external programs*" (FINK 2014). A disadvantage is the fact that the tools are structured by the kind of external application like GRASS, SAGA etc. and that they often offer the same basic tools like buffer. Consequently one will find several tools with the same functionality in different places and would have to decide which one to use. Nevertheless the search function which is available in both programs facilitates the process extremely. Another downside of using external applications is the fact that not the full functionality can be used within QGIS as could be seen with SAGA's *visibility* tool, but has to be applied under a different program structure and GUI. Moreover updates that are performed in external applications are not assigned to QGIS as could be seen with GRASS GIS *r.viewshed* update.

Nevertheless, the majority of users claimed that especially the combination of QGIS with GRASS GIS is very powerful (C6, C11, C12, C14, C16, C21). While in older QGIS versions working with external algorithms was not coherent. Today "*running them requires no prior knowledge of the external applications they use, making them more accessible for first-time users*" (QGIS DEVELOPMENT TEAM 2014: 160). With the *Processing* Plugin the external algorithms are accessible in the same way as in ArcGIS toolbox. Another difference discussed was ArcGIS comprehensive Toolbox for Spatial Statistics. QGIS does not have the same functionality in a toolbox but uses the statistics program *R* for the implementation of spatial statistics which was highlighted by several users (C11, C12, C21). Concerning this matter one could point out that "*Using external programs isn't a disadvantage, because everybody who* *would use spatial statistics would most likely have an academic background anyway and they would have worked either with SPSS or R which is just at the moment really the leading statistics package out there, so I think people would anyway be familiar. The R tools are quite convenient to implement in QGIS too, so it's quite alike the toolbox in ArcGIS. You just have to know where to look for it and this is equally true in ArcGIS*" (FINK 2014).

In the field of ***compliance*** data formats and data management were mentioned by 39% of users as important differences between ArcGIS and QGIS in the discourse analysis. The comments generally referred to data format and databases. In the first category users highlighted the importance of the number of supported formats and the interoperability with other programs. Here QGIS has the advantage that it supports all open standards as it works with the GDAL/ORG library. When the QGIS expert was asked in the interview on the strength of QGIS he stated:

"*Let's start with the most positive aspect of QGIS which is open standards…*" (FINK 2014).

Furthermore the possibilities of QGIS in the field of data conversion and its ability to handle WellKnownText (WKT) formats were highlighted (C5) by users. The majority of users put emphasis on QGIS's direct connection to databases like PostgreSQL or MySQL which supports direct edits in the database. The same is true for the connection to WebServices. In QGIS the connection works like adding a regular vector layer by typing in the web address. In ArcGIS it is more complicated to establish connections to databases or web layer. For WFS the extension Data Interoperability is needed and an Interoperability Connection to the WFS service has to be added.

A drawback for QGIS compliance is the issue that the visibility grid which was generated in SAGA had a proprietary format which needed to be converted to GeoTiff again.

9.3 Reliability

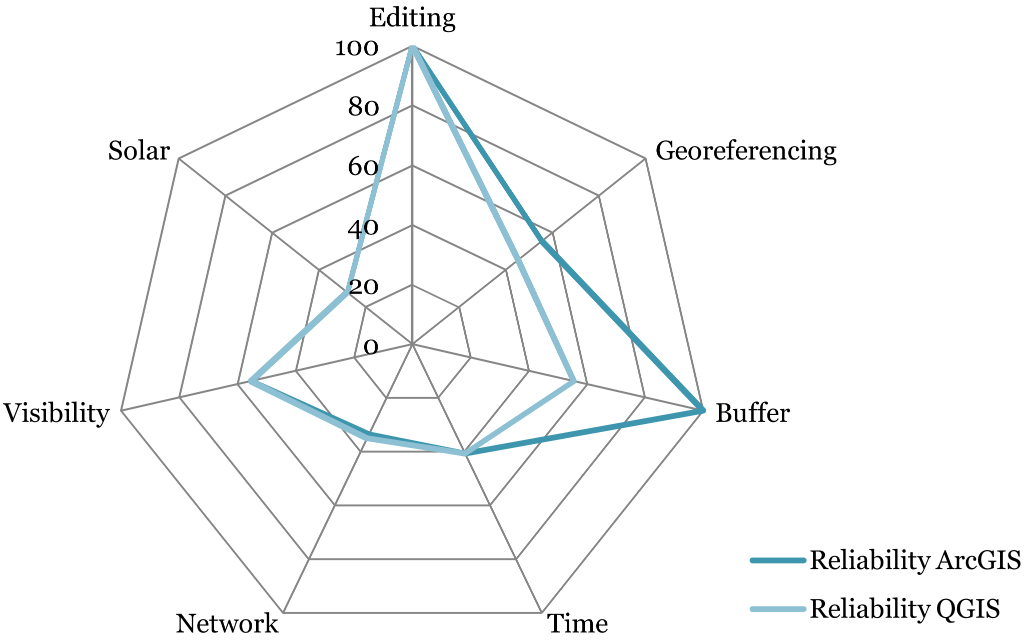


Figure 50 Comparison of Reliability

In the discourse analysis 12% of users mentioned *reliability* as a criterion. They did not prefer one of the two programs. Comments stated that QGIS was generally “less buggy” (C21) and the company made good experiences with the software (C11) while others complained about ArcGIS bugs (C24). Another user mentioned problems in QGIS while working with large imagery on background (C24). This is equally true for working with base maps in ArcGIS though.

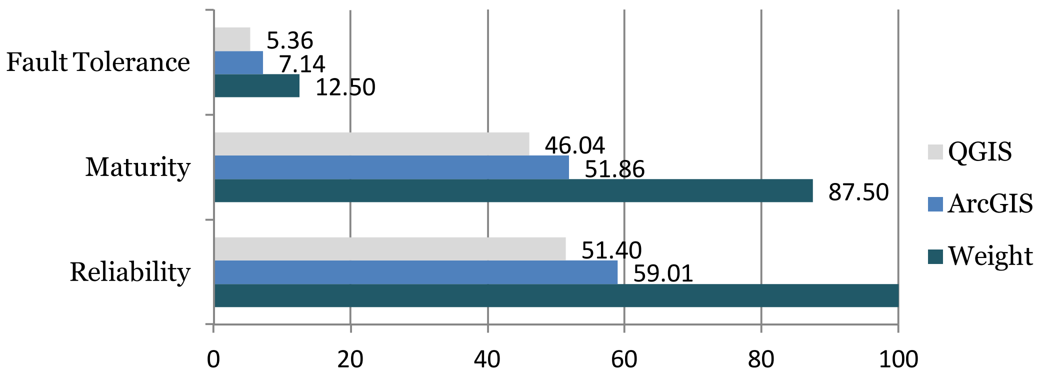


Figure 51 Quality attributes for Reliability

In the test analysis, both programs ranked rather low with 59 (ArcGIS) to 51.4 points (QGIS) on average. This is mainly due to the question on ***maturity.*** Whether the algorithm could be performed successfully on the first try was valued with 44 points. This was only true for the basic applications Editing, Georeferencing, and Buffer. The advanced analysis always required certain adoptions of settings or data quality. Other measures that needed to be undertaken were the restart of software or hardware, or the generation of new files or geodatabases. The quality attribute reliability is mostly comparable with the exception of the buffer, were SAGA did not give correct output for the multi-ring buffer.

One aspect where QGIS failed in terms of maturity was the use of GRASS or SAGA tools. Running GRASS GIS tools, like for instance Buffer regularly led to a hang up of QGIS. Furthermore there were "missing dependencies", or problems loading output layer". Moreover, the connection to GRASS 7 could not be established and the download of an add-on in GRASS 6.4 cannot be transferred to the toolbox. GRASS *r.los* tool could not be used because "*lat/long support for this model is not implemented (yet)*" Other issues were python errors which usually required a restart of the program.

Also ArcGIS produced several errors and there were some tools which could not be run at all like in QGIS. The program also produced Script errors which required a restart of the software.

Popular errors in ArcGIS are:

- Error 999999: Error executing function.
- Error 000622: Failed to execute xy. Parameters are not valid
- Error 000859: The required Zone filed is empty, or is not the type of Filed
- Error 010005: Unable to allocate memory
- Error 010016: Error in calculating xy
- Error 000210: Cannot create output
- Error 000229: Cannot open xy

Frequent errors in QGIS:

- Missing dependency. This algorithm cannot be run.
- Bad file descriptor. See log for more details.
- Problem loading output layer
- An error has occurred executing python code.
- Qgis bin exe reagiert nicht
- Crash dumped

Also ***fault tolerance,*** defined as the ability of the software to perform an algorithm despite the infringement of the specified input, could not be tested systematically. Generally the programs do not tolerate incorrect syntax in the tool windows or for queries. For the input of corrupt data, the OSM polygon feature datasets of Middle Franconia can be used. QGIS could clip them right away in catchment area analysis as well as site location analysis. With ArcGIS it was necessary to use the *repair geometry* tool which fixes problems like for instance null geometries, duplicate vertex or unclosed rings in both cases. The tool detected several geometry errors due to incorrect ring ordering. The use of *repair geometry* was also necessary before the performance of *intersection* in Step 4 of the Solar Analysis, and *dissolve*. In return several features got lost during the clip geoprocessing action with QGIS. The final file had only 70934 features while ArcGIS feature class had 73240. The performance of *Multipart to Singlepart* only revealed 70940 features.

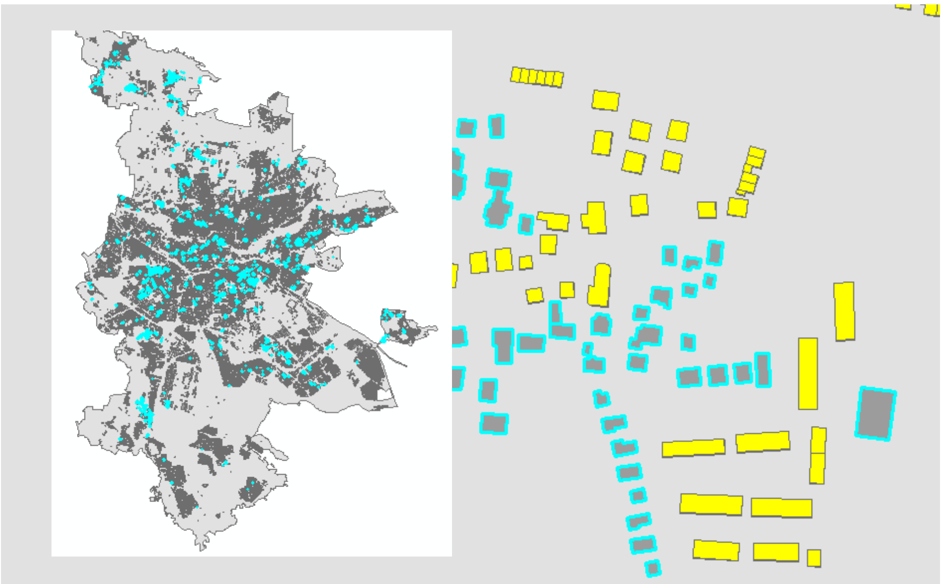


Figure 52 Missing features in QGIS (turquoise) that exist in ArcGIS

Additionally QGIS had difficulties clipping the DHM first. The algorithm had to be performed again. The aspect ***recoverability*** could not be tested systematically. It can be stated though, that temporary files got lost in both programs while data that was already saved remained untouched.

9.4 Usability

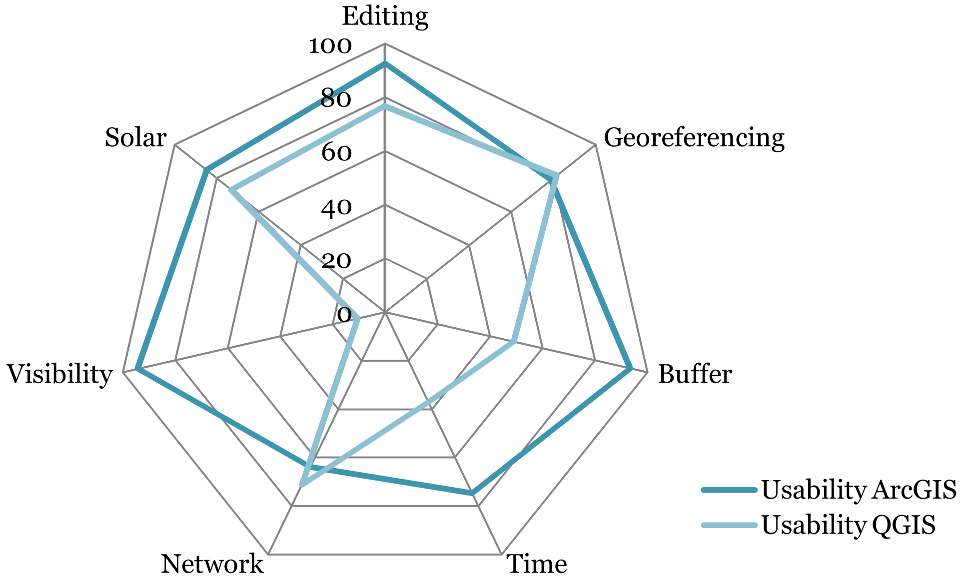


Figure 53 Comparison of Usability

Usability shows a differentiated picture in which ArcGIS generally wins with 83.2 to 57.1 points on average. Only in network analysis and Georeferencing does QGIS have a small advantage. Usability was especially low for the visibility analysis because the algorithm had to be performed in SAGA GIS and there was no documentation for the algorithm at all, not even in the internet. Also for the generation of time enabled maps usability was half as low for QGIS because there was no documentation in the official help and the handling had to be learned in five different websites.

In ***understandability*** QGIS ranks behind ArcGIS as the appropriated tools could often not be found intuitively in the program but instead required research. In ArcGIS the tools can be found via a search function in the toolbox and the required toolbars can be added in through the main menu. In QGIS the tools sometimes need to be installed as plugins first. A search in the official manual is not always successful as not all plugins are documented here. Furthermore, QGIS frequently has multiple tools for the same functionality available due to the bindings to GRASS and SAGA. However it also has a search function for the processing toolbox which facilitates the search. Regarding the access to the tools through submenus, the programs are about even. QGIS has more tools though with unique icons compared to ArcGIS. As an example the geoprocessing tools can be named which all have a hammer icon in ArcGIS but unique ones in QGIS. Moreover QGIS has larger symbols which make the work for beginners easier.

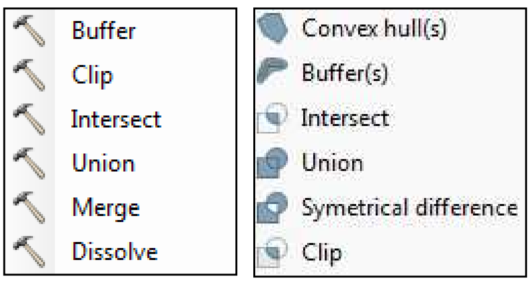


Figure 54 Geoprocessing Tools in ArcGIS [left] and QGIS [right]

Concerning **learnability** ArcGIS wins over QGIS. For QGIS functions there is often no documentation for the specific tool available in the official help, especially for plugins. Rather the internet needs to be consulted. The search in the internet has the disadvantage that one has to consider whether the information is still up to date due to the fast development of QGIS. Moreover it is often necessary to find the desired information on different websites or forums. The poor documentation was also named in the discourse analysis. Another disadvantage of the documentation is the fact that the German QGIS manual is not completely translated yet, but contains English sections. This is also true for charts and Screenshots in ArcGIS Help. Anyhow, ArcGIS has an integrated Help tab for each tool available which explains the specific settings. Although QGIS has an integrated tab it generally states "*Sorry, no help available*". The GRASS and SAGA tool do have an integrated Help.

Another constraint of QGIS documentation was the lack of explanation for the underlying scientific principles of the algorithm. In this way, it was hard to compare the program's results, especially for different outcomes. As an example SAGA's visibility tool or the road graph can be named. In GRASS the background information is explained in detail though, as for the *r.sun* tool.

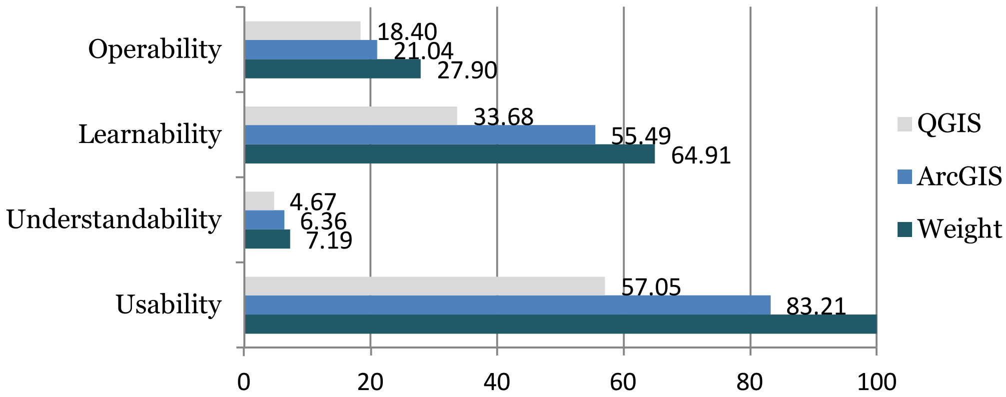


Figure 55 Quality Attributes for Usability

In ArcGIS there is detailed documentation on the tools available in the ArcGIS resource center. Due to the great number of information it is sometimes hard to find the desired one, although there is usually a section available that gives a quick tour of the tool.

In terms of ***operability*** QGIS was slightly behind ArcGIS in the test analyses. Both programs usually have default settings for the tools which facilitate their operability. The query builders have templates for the input. But in QGIS, respectively GRASS GIS some input had to be generated freely. This was the case for the classification of the raster dataset where an external .txt file was created that determines the classes according to a defined syntax. In addition, GRASS select tool does no supply templates but the SQL statements need to be entered from memory.

Further positive aspects in both programs are the existence of an undo button, and the possibility to overwrite output if it's specified in the settings. Newly generated layers can automatically be added to the TOC. Furthermore, both programs give visual feedback for an active calculation process. ArcGIS has the tools name running in the lower right corner which shows the percentage in between. When the tool is run within a model it even shows the number of processed features. QGIS has a status bar that shows the progress in percent.

A downside in both programs is the necessity to activate extensions or plugins. QGIS has the advantage that a tool that is not activated does not show up in the interface. In ArcGIS this is however the case which can lead to the problem of running a tool that fails because the extension is not yet activated. Moreover, ArcGIS and QGIS can be confusing with unexpected responses. As examples scripting errors or unexpected geoprocessing outcomes can be named.

Another negative aspect that ArcGIS and QGIS share is the absence of adequate information in error messages. This is especially crucial as the troubleshooting usually requires more time than the running of the algorithms. In the previous section on reliability it became obvious, that the analysis can hardly be performed on the first try. In ArcGIS the geoprocessing results are stored in the reprocessing results window, and can be looked up at any moment. In QGIS the results can be found in the log file. However they do not contain detailed information on errors.

Moreover there is a difference in the access of the tools for example the symbology settings. While in QGIS all cartographic functionalities can be accessed through a maximum of 2 windows, it can be up to 5 in ArcGIS. The QGIS symbology could be used intuitively without searing or consulting the help.

"QGIS symbology is better than ArcGIS. It was developed from academics with usability centered studies and from cartographers, graphic designers and, communication researchers. It's really powerful right now and straightforward to use, while in ArcGIS you still have the dialogue from the mid 90's where you have to search or know exactly where to click. That becomes better and better in QGIS…" (FINK 2014).

In the discourse analysis users preferred ArcGIS. The highlighted the convenience of "out-of-the box" tools (C9), stated that ArcGIS is generally easier to use, (C13, C16) and that QGIS and GRASS need a lot of training as they are "not so consistent" (C16). The judgment was not unanimous though. There were also users that assessed QGIS as user-friendly (C19).

A closer look at the consistency of the programs structure shows that the interface design of both programs fulfill the design principles for cartographic applications direct manipulation, menu selection, symbols, visual feedback, and form fill in. The graphic design elements color, size, font, fill, form, direction, and transparency are used consistently within all levels of the applied tools. Even SAGA and GRASS tools have the same interface as QGIS internal algorithms. Regarding the language however both programs are inconsistent. In both programs certain dialogues will be displayed in the system language [German] despite an English installation. Although the language can be changed in QGIS, the change is not transferred to all aspects. Interestingly the log files in GRASS GIS were in German although the tools and the help are in English.

The structure of the programs themselves is hard to compare. It is a fact though that the integration of external algorithms in QGIS represent a challenge for a consistent handling. However, there has been a constant improvement with each new version. Before the integration of SEXTANTE alias processing toolbox the files had to be imported and exported while the tools can now be used out of the box.

"I think it [QGIS] becomes more and more [consistent] and it becomes more and more ahead of ArcGIS because ArcGIS is also not consistent in itself, you can see that it is historically grown and that parts stem from a different era than other parts and that's the same for QGIS but it has this attempt and the people involved who try to make the user interface more consistent. I wouldn't say QGIS is ahead of ArcGIS, they are definitely catching up and ArcGIS is also not a role model" (FINK 2014).

9.5 Efficiency

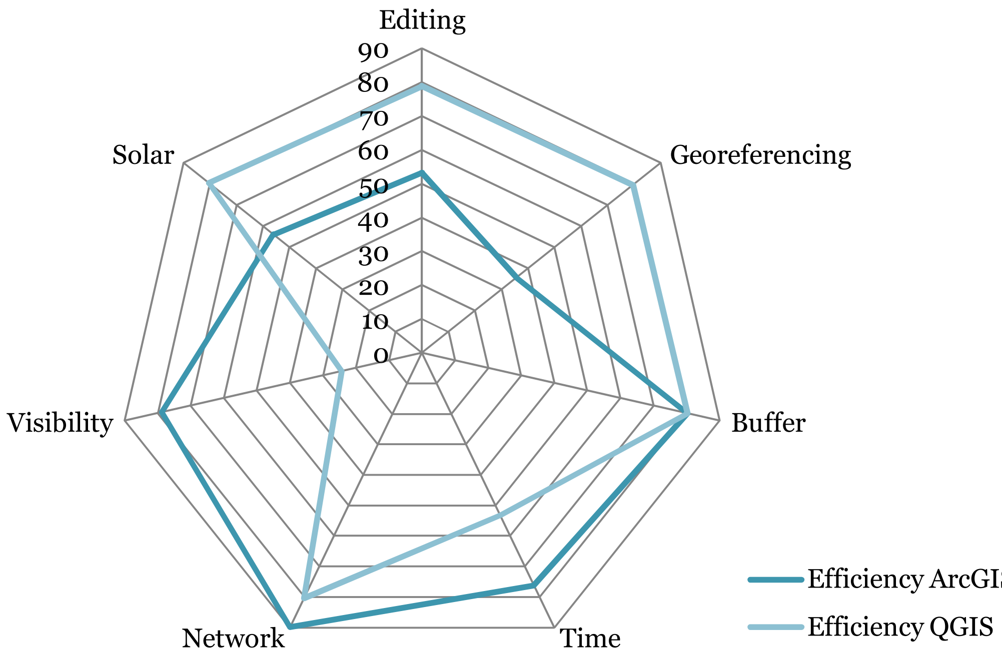


Figure 56 Comparison of Efficiency

In total the programs are relatively even for the software quality attribute ***efficiency*** with 67.2 (ArcGIS) to 68.1 (QGIS) points on average. The results vary strongly though between the analyses. ArcGIS wins in Visibility Analysis, Network Analysis, and Time Slider while QGIS scores higher for Editing, Georeferncing, and location analysis for Solar Panels.

Concerning ***resources*** it is often necessary in ArcGIS to activate extensions (visibility, solar, network) while QGIS required the activation of plugins, which requires an internet connection. In both programs the user has to apply several tools to achieve the desired actions.

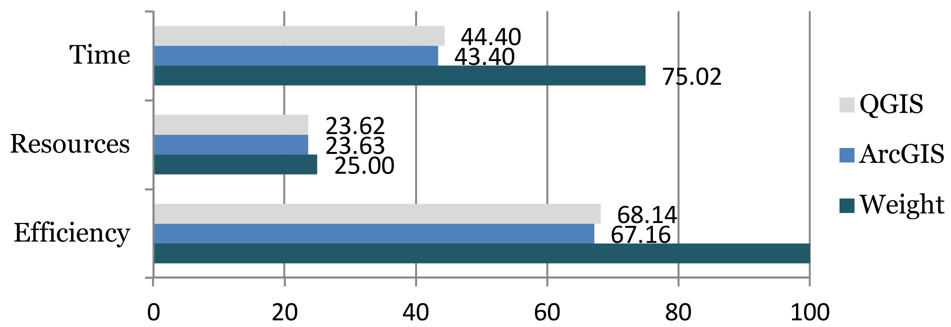


Figure 57 Quality Attributes for Efficiency

QGIS has the disadvantage compared to ArcGIS that it could not perform all the analyses within the program but needed the support of SAGA GIS for the visibility analysis or the text editor to generate a classification file.

15% of the users made comments on the program's efficiency in the discourse analysis which all referred to ***speed***. All users claimed better performance of QGIS in terms of its speed due to GDAL/OGR functions written in Python (C9, C21) and quicken starting times (C7, C30). Another user emphasized not to "*expect performance*" (C24) from ArcGIS. The starting time was indeed shorter in QGIS in the beginning with 3 sec compared to 10 in ArcGIS, but became slower with the installation of more plugins and went up to 8sec.

Nevertheless the geoprocessing performance was not better in QGIS, rather ArcGIS wins in terms of speed for the performed geoprocessing algorithms *buffer, intersect, union, erase/difference,* and *dissolve* on vector data. Additionally QGIS can only perform union for two feature classes while ArcGIS can handle more at one time. QGIS was faster though in working with projections with vector and raster data.

Vector Data	**ArcGIS [min:sec]**	**QGIS [min:sec]**
Buffer Waterways 50m	0:05	3:14
Buffer Railways 5m	0:05	4:07
Union Water/Road/Rail	1:02	32:10
Intersect Potential	0:02	0:12
Zonal Statistic	0:02	14:16
Clip Buildings	0:38	15:15
Clip Natural	0:01	0:10
Project Buildings	1:55	0:38
Project Natural	0:11	0:04
Project Landuse	0:17	0:03
Project Roads	0:58	0:29
Raster Data		
Project DHM	0:15	0:03
Slope/r.slope	0:32	0:04
Area Solar Radiation/r.sun	5h 07:32	20:02
Visbility	0:07	22:00

Table 26 Selected benchmarks for the Calculations of a Solar Park

In terms of the number of steps that are required to perform the analysis, QGIS was superior. For the option to *automate processes* without programming skills ArcGIS however has the lead. The model builder is an appropriate tool to accumulate different algorithms while QGIS modeler failed in terms of usability. The parameters cannot be named but only get numbers (output 1, Output 2, output 3...) which makes it impossible to build larger models. As a result, the location search for solar panels was implemented with a model in ArcGIS, but not in QIGS.

Another aspect influencing the speed was the availability of default settings, in which the programs are even, but for the overall number of steps that is required to perform a specific analysis the results differ. QGIS proved to be more efficient for simple tasks like georeferencing or editing. In ArcGIS the user has to make a huge effort for the data preparation, for instance in the network analysis with establishing the network. Once it is done though, it can be used more efficiently for several analyses while in QGIS all routing points needed to be set all over again for each participant.

9.6 Maintainability and Portability

Maintainability and Adaptability could not be evaluated in the test analysis as this is usually done with static testing instead of dynamic. Still several aspects can be highlighted.

In the category ***maintainability***, in terms of ***analyzability***, which aims at the questions whether it is possible to extend the functionality with the user's own scripts both programs score equal. ArcGIS and QGIS can be extended with python scripts. Both programs provide a library with functions and a platform to share the programmed scripts amongst other users. The ***stability*** of the programs could also be proven. Therefore files that were produced in one of the programs were loaded into the other software. This was implemented for the comparison of the results or to run the algorithm with the basic file of the competitor to see if the input data quality caused a differing result. ArcGIS and QGIS could both read and calculate with the files of the other software.

Testability and ***changeability*** are only given for QGIS. The source code is openly available and can be adopted according to the user's needs. Users can write plugins with the integrated Plugin Builder in QGIS or through the creation of their own fork on QGIS repository at *Github*. Additionally there is the PyQGIS cookbook.

In the category ***portablity***, for ***adaptability*** the software's capability to be integrated into different environments without applying actions or means other than those provided for this purpose for the software considered, needs to be evaluated. In this context QGIS has an advantage over ArcGIS as it has bindings to other OS programs GRASS GIS, SAGA GIS, Orfeo toolbox OTB for photogrammetric, OSSIM for image processing and is compatible with the leading statistic program R.

In terms of ***installability*** QGIS wins as it runs on all common platforms Windows, Mac, Linux, BSD with Android under development while ArcGIS only runs on Windows. This fact was mentioned by around ten percent of the users in the discourse analysis. Nine percent of users highlighted this fact. Also for ***compliance*** QGIS has an advantage because it works with open standards and can easily connect to PostGIS databases as has already been discussed under the section functionality. The aspect of data formats and data management was named by 39% of users and thus represents the fourth most popular answer. It is also an advantage that QGIS uses the resources of other OS Software packages because these programs are also developed further and a QGIS user has access to the functionality of specific software under a known interface.

Concerning ***replaceability*** QGIS also has the lead. While it could replace an ArcGIS version in the same environment, ArcGIS could not do the same for QGIS as it only runs on Windows. Nevertheless it needs to be stated that QGIS does not have the same functionality as ArcGIS. QGIS cannot undertake the same operations or at least not without programming.

In the discourse analysis 27% of users mentioned aspects concerning the *portability* of the two programs. Users agreed that QGIS is highly customizable with the plugins, source code, batches, and libraries. It was further mentioned that QGIS is flexible and expandable while ArcGIS is limited when integrating into ones own workflow (C16). Other users highlighted the importance of scripting support for a GIS system (C4) and that both programs can be extended through scripting (python) and plugins (C30).

In this context a case can be named that was found during the internet research:

> Planner and GIS Analyst MELTZ launched a test with ArcGIS 10.0 and QGIS 1.4.0 in June 2011 while working on a project which covered a five-town area in the USA. His aim was to process a clip Geoprocessing operation with a 1.3GB .shp-file with 20'

contour lines and a 1 mile buffer of the study area to which it was supposed to be clipped.

In ArcGIS operation he used the version ArcGIS 10, SP2 with Windows 7, 64 bit on a Dell Precision m2400 laptop, Intel Core 2 Duo CPU, 3.06GHz, 8 GB RAM. The operation failed after twelve hours and gave out an error message stating "*bad geometry in the output*".

For the QGIS operation the version QGIS 1.4.0 was used with Ubuntu 11.4 on a Dell Inspiron 600m laptop, Intel Pentium M CPU, 1.60 Ghz and 1GB RAM. The process took 17 minutes and 21 seconds to complete successfully (MELTZ 2011). MELTZ run further tests and tried to change the data quality by using ArcGIS *Check Geometry* tool *Repair Geometry* tool which fixed five "Null-Geometries" and ET GeoWizard's *Fix Geometry*. Anyhow, he could still not clip the features and the process stopped after 1 hour 35 minutes and 42 seconds and showed an error warning for an Invalid topology (MELTZ 2011b).

The case launched a discussion on the internet and gained the attention of a ESRI employee who further investigated the case and brought to light that there was a bug in ArcGIS clip operation "*that was exposed by a number of the contour lines having 500k vertices which span nearly the entire extent of the data. The clip algorithm was sub-optimal for data matching these criteria*" (KEN/ESRI 2011). The bug was fixed by ESRI for the 10.1 release and brought the time down to approximately the same amount of time as what you reported for QGIS (KEN/ESRI 2011).

This case shows the disadvantage of working with software which has a proprietary source code. The user cannot analyze, test, or change the software but is at the mercy of the product. Even if the user him- or herself does not have the required programming skills to detect and fix a bug, the case can be brought to an interested community which has been proven to exist. In the case of QGIS the reported and fixed bug could have been made available as a plugin instantly while for ArcGIS the user has to wait for the new release.

10 Summary

The aim of this thesis was to give spatial planning offices a scientific base to decide whether the implementation of the OS GIS QGIS instead of ArcGIS is possible for their specific tasks. Therefore the parameters, development, and distribution, cost and licenses, training and support as well as software structure and functionality of the two programs were compared. Furthermore test analysis in the field of spatial planning were conducted and evaluated according to ISO's quality attributes functionality, reliability, usability and efficiency, while maintainability and portability were analyzed separately.

"It is about different needs, there are definitely use cases where one of the two is better suited" (FINK 2014).

While ArcGIS represents the leading proprietary GIS software with more than 1 Million users worldwide and an expansion that started out in the 1980ies, the OS GIS software QGIS is a comparably young software that began development in 2002 and has around 100.000 users with a growing market especially in Europe. The cost for an ArcGIS license can be up to 25.000 Euros depending on the version and number of extensions while QGIS is an OS product and is available for free and its code can be adapted. Compared to the well established training and support structure of ArcGIS, QGIS still needs to catch up, although there are also companies offering commercial support worldwide.

Regarding the quality attribute ***functionality*** in the category *suitability,* ArcGIS does not win in the performed analysis as they were chosen so that they could more or less be performed by both programs, however for the overall provision of tools it certainly does. ArcGIS provides more raster and vector algorithms 'out-of-the-box' which can only be implemented with python programming in QGIS. However, the evaluation of cartographic functionality over time has shown that QGIS is catching up really quickly which is reflected in the fact that a new QGIS version is released about each fourth month. The *accuracy* of the delivered results was comparable. For *interoperability* QGIS has the lead though as it uses the functionality of the OS programs GRASS GIS, SAGA GIS, Orfeo toolbox OTB for photogrammetric, OSSIM for image processing and is compatible with the leading statistic program R. Also in the category *compliance* QGIS is superior to ArcGIS as it uses open standards. While ArcGIS supports over 100 data formats which only include limited OGC data formats QGIS uses the OS translation library GDAL/ORG which supports over 200 vector and raster formats including all common web services. Also for databases ArcGIS generally uses the proprietary ESRI Personal-, File-, and ArcSDE database while QGIS uses OS SpatiaLight databases and supports PostgreSQL/PostGIS. The quality attribute ***reliability*** is rather low in both cases, which is not surprising due to the complexity of GIS software in general and the processing of large data on a on Samsung Q330 laptop, Intel Core i3 CPU, 2.27GHz, 4 GB RAM with Windows 7, 64bit. Concerning *maturity* the analyses could mostly not be performed on the first try but adoptions of setting, data quality or management were necessary. Both software showed unexpected answers and defect messages that do not point to the nature of the problem. Also in terms of *fault tolerance* both programs rank equally low. In ***usability*** none of the software has a clear advantage. In *learnability* ArcGIS clearly wins as it has complete documentation in the official Help and the tools themselves while QGIS documentation is incomplete, especially for plugins. In *understandability* and *operability* both rank equally though. One the one hand, the use of the external programs makes QGIS inconsistent, while on the other hand its interface is developed by usability experts. It can be used intuitively, as could be seen in the analysis of the symbology, while

ArcGIS is disadvantaged because it is historically grown which makes it more inconsistent. For the quality attribute ***efficiency*** ArcGIS scored higher. Regarding the *resources* ArcGIS and QGIS ranked about equally low since the activation of extension and plugins was frequently required. ArcGIS mostly showed a higher *speed* than QGIS for the processing time, yet QGIS required less steps to perform the analysis. For ***maintainability*** QGIS holds certain advantages. *Analyzability* and *stability* are even because both programs can be extended with python scripting and the files can be used in other programs. *Testability* and *changeability* however are won by QGIS because its source code is openly available. Concerning the quality attribute ***portability*** QGIS wins it all categories. It is more *adaptable* as it has several bindings to other software programs. It scores higher in *installability* because it exists for all common operating systems whereas ArcGIS only runs on Windows. It dominates in *compliance* due to the use of open standards. Finally QGIS has a higher potential for *replaceability* of other programs since it runs on different operating systems and uses open standards.
It could be shown, that QGIS has a clear advantage in maintainability and portability while ArcGIS wins in suitability. For the quality attributes efficiency, reliability, and usability no software can be put ahead but the results depend on the specific analysis. Furthermore usability can be perceived quite differently by individual users. QGIS can be easier to handle for beginners since it provides less functionality and thus options, but the weak documentation is a disadvantage though. For basic applications QGIS is suitable or even more suitable than ArcGIS due to the higher usability. This is the case for editing or georeferencing. The integration of external algorithms is more complicated, however for advanced users it is suitable. In the end, a GIS program needs to be handled by an expert as geographic knowledge, for instance on coordinate systems, is required. Each office needs to decide whether they would rather invest in human resources or software licenses.

Anyhow, ArcGIS does provide more analysis tools out of the box than QGIS. When specific functionality is needed like advanced network analysis, which is an important part of spatial planning, ArcGIS cannot be replaced unless the required tools are programmed. However QGIS is catching up at a remarkable rate and its developing potential is very high since it can use the functionality of other OS programs which are also being developed further. Moreover its high portability and maintainability contribute to the quick progress. Nevertheless, ArcGIS is still the leading GIS software and is not remaining static, but is instead transforming and adapting to the new developments in the OS community. ESRI has taken up the open source idea of sharing code by creating a presence on *Github* where users can share their python scripts. Furthermore Esri started to support OGC standards as can be seen with the Editor for OpenStreetMap. In this sense, the rise of QGIS is not just positive for QGIS users, but also ArcGIS users as competition is generally good for product development.

No matter in which direction the development of either ArcGIS or QGIS will go; the keynote of this thesis is still true. For each user and each use case either ArcGIS or QGIS will be more appropriate and it is the user who will have to decide.

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- http://www.gislounge.com/qgis-versus-arcgis/
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Annex

Interview Guideline

Interview QGIS – Christoph Fink
Date: 23.05.2014
Place/Time: Weltcafé, Wien 14.30Uhr

1. What is your professional background and what is your relation to QGIS?

2. Open Source- Proprietary Software?
    - Main difference apart from the price?
    - Advantages and disadvantages of QGIS

3. How does the QGIS community work?
    - Employed developers?
    - Role of User groups?
    - QGIS support/workshop?
    - Project Steering Committee?
    - Users? Academia? Companies?
    - Financing via development contracts

4. In which fields is QGIS ahead of ArcGIS, in which fields does it still need to catch up?

    - Development Process/ Distribution/ Cost & Licenses/*Training & Support/* Structure & Tools/ Data Management/ Mapping & Visualization/ Editing & Geoprocessing/Projections/Geocoding/ Spatial Analysis/ Usability

5. Usability
    - Which skills does one need to work with QGIS?
    - Reliability? Speed?
    - Problems with the QGIS lifecycle, old project cannot be opened in a new version
    - *"when you don't have programming skills you need to use ArcGIS*
    - *"enterprise teams should choose commercial while private users should go with open source"*
    - *"QGIS and GRASS need a lot of training compared to ArcGIS"*
    - *"QGIS is not so consistent"*
    - *"It's a question of personal preference"*

6. Distribution/Trends:

"Over the last couple of years open source software has done a ninja attack, the quality of the FOSS GIS software now is nothing more that remarkable" (DUGGAN 2013).

- Information on distribution?
- Further development goals?
- Which role will QGIS play in the future?

Discourse Analysis Comments

	Comment Nr.	User	Date
Stack Exchange	Comment2	User "Mapperez"	Oct 11 '12 at 15:19
	Comment3	User "Naught101"	Apr 5 '13 at 23:33
	Comment4	User "U2ros"	Oct 11 '12 at 7:31
	Comment5	User "elrobis"	Apr 17 '13 at 16:57
	Comment6	Giovanni Manghi	Feb 2 '12 at 21:32
	Comment7	User "underdark"	Feb 3 '12 at 8:06
	Comment8	User "elrobis"	Feb 3 '12 at 17:05
	Comment9	User "MappaGnosis"	Feb 3 '12 at 9:47
	Comment 10	User "PolyGeo"	May 5 at 5:04
Researchgate	Comment 11	Nils Noelke · Georg-August-Universität Göttingen	Nov 2, 2012 & Nov 1, 2012
	Comment 12	Georg Hörmann · Christian-Albrechts-Universität zu Kiel	Feb 25, 2013 & Jul 14, 2013
	Comment 13	Cédric Laizé · Centre for Ecology & Hydrology	Nov 2, 2012
	Comment 14	Bharath Setturu · International Institute of Information Technology, Hyderabad	Nov 2, 2013, Nov 10, 2012 & Dec 6, 2012
	Comment 15	William Church · The University of Western Ontario	Nov 8, 2012
	Comment 16	Matthias Meißer · University of Rostock	Nov 11, 2012
	Comment 17	Mohamed Eleiche · University of West Hungary, Sopron	Nov 15, 2012
	Comment 18	Craig Smeaton · University of St Andrews	Nov 25, 2012
	Comment 19	Selvam .S · V.O.Chidambaram College	Nov 26, 2012
	Comment 20	Francesca Remigi · Indipendent Researcher	Nov 26, 2012
	Comment 21	Tyler Frazier · Technische Universität Berlin	Dec 5, 2012
	Comment 22	Andrius Kučas · Nature Research Centre	Dec 6, 2012
	Comment 23	Filippo Catani · University of Florence	May 22, 2013
	Comment 24	Juilson Jubanski · Remote Sensing Solutions GmbH	May 24, 2013
	Comment 25	Nicolas Hess · Hochschule für nachhaltige Entwicklung Eberswalde	Jun 25, 2013
	Comment 26	Julia Law · University of Adelaide	Jul 13, 2013
	Comment 27	David Ndegwa Kuria · Dedan Kimathi University of Technology	Aug 14, 2013
	Comment 28	Mohammad Firoz Khan · Jamia Millia Islamia	Dec 6, 2013
	Comment 29	Afaq Ahmad · Sultan Qaboos University	Dec 7, 2013
GIS Lounge	Comment 30	Morais Dempsey Caitlin	Nov 4, 2012
The Spatial Blog	Comment 31	Nicholas Duggan	Nov 29, 2013
Don Meltz	Comment 32	Don Meltz – Planning & GIS Spatial Planner	June 11, 2011
	Comment 33	Mars Sjoden	June 11, 2012

AHP Matrices

1.Quality Attributes

Functionality	Suitability	Accuracy	Interoperability	Compliance	**Priority**
Suitability	1	1	9	7	**44.0**
Accuracy	1	1	9	7	**44.0**
Interoperability	1/9	1/9	1	1/3	**4.0**
Compliance	1/7	1/7	3	1	**8.0**
					100

Suitability	Tool	Adaption	Variety	**Priority**	**Overall Priority**
Tool	1	7	7	**77.8**	**34.2**
Adaption	1/7	1	1	**11.1**	**4.9**
Variety	1/7	1	1	**11.1**	**4.9**
				100	**44**

Usability	Understandability	Learnability	Operability	**Priority**
Understandability	1	1/7	1/5	0.07
Learnability	7	1	3	0.65
Operability	5	1/3	1	0.28

Understandability	Help	Sublevels	Search Function	Internet	**Priority**
Help	1	7	7	1/3	0.30
Sublevels	1/7	1	1	1/9	0.05
Search Function	1/7	1	1	1/9	0.05
Internet	3	9	9	1	0.60

Learnability	Language	Default	Documentation Help	Help Window	Integration Help Window	Background	Error Messages	**Priority**
Language	1	3	1/5	1/3	5	1/3	1/3	0.07
Default	1/3	1	1/7	1/7	3	1/7	1/7	0.03
Documentation Help	5	7	1	1	7	3	1	0.26
Help Window	3	7	1	1	7	1	1	0.20
Integration Help Windov	1/5	1/3	1/7	1/7	1	1/7	1/7	0.02
Background	3	7	1/3	1	7	1	1/3	0.17
Error Messages	3	7	1	1	7	3	3	0.24

Operability	Sublevels	Symbols	Coherence	Response	Visual Feedback	Overwrite	Revoke	New Layer	Plugins	**Priority**
Sublevels	1	3	3	3	3	1	1	1	5	0.18
Symbols	1/3	1	1	1	1	1/3	1/3	1/3	3	0.06
Coherence	1/3	1	1	1	1	1/3	1/3	1/3	3	0.06
Response	1/3	1	1	1	1	1/3	1/3	1/3	3	0.06
Visual Feedback	1/3	1	1	1	1	1/3	1/3	1/3	3	0.06
Overwrite	1	3	3	3	3	1	1	1	5	0.18
Revoke	1	3	3	3	3	1	1	1	3	0.18
New Layer	1	3	3	3	3	1	1	1	5	0.18
Plugins	1/5	1/3	1/3	1/3	1/3	1/5	1/5	1/5	1	0.03

Efficiency	Time	Resources	**Priority**
Time	1	3	0.75
Resources	1/3	1	0.25

Time	Default	Steps	Processing Time	Automation	**Priority**
Default	1	1/3	1/7	1/5	0.06
Steps	3	1	1/5	1/3	0.12
Processing Time	7	5	1	3	0.57
Automation	5	3	1/3	1	0.26

Resources	Programming	Tools	Internal Algorithm	Plugins	Internet	**Priority**
Programming	1	3	5	7	9	0.06
Tools	1/3	1	3	5	7	0.26
Internal Algorithn	3	1/3	1	3	5	0.13
Plugins	1/7	1/5	1/3	1	3	0.51
Internet	1/9	1/7	1/5	1/3	1	0.03

Reliability	Maturity	Fault Tolerance	**Priority**
Maturity	1	7	**0.875**
Fault Tolerance	0.14	1	**0.125**

Maturity	First Try	Completed	Defects	Crashes	Restart Software	Restart Hardware	New Project	New Geodatabase	Data Quality	**Priority**	**Overall Priority**
First Try	1	7	9	9	9	9	9	9	9	**0.48**	**0.42**
Completed	1/7	1	9	7	9	7	9	9	9	**0.25**	**0.219**
Defects	1/9	1/9	1	1/3	1	1/3	1	1	1	**0.03**	**0.026**
Crashes	1/9	1/7	3	1	3	1	3	3	3	**0.06**	**0.053**
Restart Software	1/9	1/9	1	1/3	1	1/3	1	1	1	**0.03**	**0.026**
Restart Hardware	1/9	1/7	3	1	3	1	3	3	3	**0.06**	**0.053**
New Project	1/9	1/9	1	1/3	1	1/3	1	1	1	**0.03**	**0.026**
New Geodatabase	1/9	1/9	1	1/3	1	1/4	1	1	1	**0.03**	**0.026**
Data Quality	1/9	1/9	1	1/3	1	1/5	1	1	1	**0.03**	**0.026**

2. Matrices – Suitability

Buffer	Fixed Buffer	Attribute Buffer	Multiple Ring	Variable Distance	**Priority**	**Overall Priority**
Fixed Buffer	1	3	5	5	55.96	24.62
Attribute Buffer	1/3	1	3	3	24.95	10.98
Multiple Ring	1/5	1/3	1	1	9.55	4.20
Variable Distance	1/5	1/3	1	1	9.55	4.20
					100.00	44.00

Time Slider	**Time**	**Multiple Layer**	**Settings**	**Visualization**	**Export**	**Priority**	**Overall Priority**
Time	1	3	3	3	3	43	18.86
Multiple Layer	1/3	1	1	1	1	14	6.29
Settings	1/3	1	1	1	1	14	6.29
Visualization	1/3	1	1	1	1	14	6.29
Export	1/3	1	1	1	1	14	6.29
						100	**44.00**

Network	Distance	Speed	Network	Tolerance	Stops	Oneway	Direction	Hierarchy	Export Shp	**Priority**	**Overal**
Distance	1	1	3	5	3	3	5	5	3	24.15	10.63
Speed	1	1	3	5	3	3	5	5	3	24.15	10.63
Network	1/3	1/3	1	3	1	1	3	3	1	9.95	4.38
Tolerance	1/5	1/5	1/3	1	1/3	1/3	1	1	1/3	3.77	1.66
Stops	1/3	1/3	1	3	1	1	3	3	1	9.95	4.38
Oneway	1/3	1/3	1	3	1	1	3	3	1	9.95	4.38
Direction	1/5	1/5	1/3	1	1/3	1/3	1	1	1/3	3.77	1.66
Hierarchy	1/5	1/5	1/3	1	1/3	1/3	1	1	3	6.07	2.67
Export Shp	1/3	1/3	1	3	1	1	3	1/3	1	8.25	3.63
										100.00	**44.00**

Visibility	Visibility	Target	Obsever	Range	Direction	Angle	**Priority**	**Overall Priority**
Visibility	1	3	3	5	5	5	42.31	18.62
Target	1/3	1	1	3	3	3	18.61	8.19
Observer	1/3	1	1	3	3	3	18.61	8.19
Range	1/5	1/3	1/3	1	1	1	6.82	3.00
Direction	1/5	1/3	1/3	1	1	1	6.82	3.00
Angle	1/5	1/3	1/3	1	1	1	6.82	3.00
							100.00	**44.00**

Solar	**Time**	**Multiple Layer**	**Settings**	**Visualization**	**Export**	**Priority**	**Overall Priority**
Time	1	3	3	3	3	43	18.86
Multiple Layer	1/3	1	1	1	1	14	6.29
Settings	1/3	1	1	1	1	14	6.29
Visualization	1/3	1	1	1	1	14	6.29
Export	1/3	1	1	1	1	14	6.29
						100	**44.00**

Georeferencing	Coordinates	Dataset	Save GCP	Edit GCP	Transformations	Resampling	View	Shape	**Priority**	**Overall Priority**
Coordinates	1	1	3	5	5	5	3	3	**26.9**	**11.8**
Dataset	1	1	3	5	5	5	3	3	**26.9**	**11.8**
Save GCP	1/3	1/3	1	3	3	3	1	1	**11.1**	**4.9**
Edit GCP	1/5	1/5	1/3	1	1	1	1/3	1/3	**4.3**	**1.9**
Tranformations	1/5	1/5	1/3	1	1	1	1/3	1/3	**4.3**	**1.9**
Resampling	1/5	1/5	1/3	1	1	1	1/3	1/3	**4.3**	**1.9**
View	1/3	1/3	1	3	3	3	1	1	**11.1**	**4.9**
Shape	1/3	1/3	1	3	3	3	1	1	**11.1**	**4.9**
									100.0	**44.0**

Supported Data Formats

#Vector	**ArcGIS**	**QGIS**
ESRI Shapefile	yes	yes
ESRI ArcSDE	yes	[read only]
ESRI Personal GeoDatabase	yes	[read only]
ESRI FileGDB	yes	no [only if SDK is installed]
DXF	yes	yes
SVG	yes	yes
GML	yes	yes
GPX	yes	yes
KML	yes	yes
AutoCAD DXF	yes	yes
AutoCAD DWG	yes	[read only]
GRASS vector format	no	[read only]

Figure 58 Supported Vector Formats in ArcGIS and QGIS [Selection]

#Raster Formats	**ArcGIS**	**QGIS**
GDAL Virtual	[read only]	yes
ArcSDE Raster	yes	[read only]
Arc/Info ASCII Grid	yes [Extension]	yes
GRASS ASCII Grid	no	yes
GRASS Raster	no	[read only]
R Object Data Store	no	yes
SAGA GIS Binary format	[read only]	yes
IMG	yes	yes
TIFF/TFW	yes	yes
JPEG, JPEG 2000, JPGW	yes	yes
GIF	yes	yes
PNG	yes	yes
BMP	yes	yes
DEM	[read only]	

Table 27 Comparison of Selected Raster Data Formats

Carto Evaluation Method

A Map construction

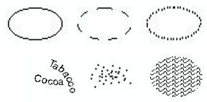
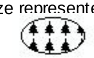
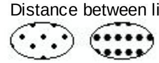
P	GOAL	QUESTION	ANSWER ArcGIS	ANSWER QGIS	WEIGHT	SCORE ArcGIS	SCORE QGIS	EXPLANATORY NOTES
					15.00			
1. Map outline					3.00			**Map outline** is a geometric-graphic base of a map. It is a system of fixed construction points or lines, which determine map face (coordinate grid, inner map frame, some bearing points, territorial boundaries). Note: *This is usually definition of a map window in programs.*
1	**G: Variability of map outline creation (max. 10 %)**				0.84			
	M: 0 - no 1 - yes	Q: Is it possible to set map outlines?	1	1	0.10	0.10	0.10	
2	**G: Cartographic map outline (max. 80 %)**							
	M1: 0 - no 1 - yes	Q1: Is it possible to set map outline in a specific cartographic projection?	1	1	0.16	0.16	0.16	Cartographic projection - mathematically defined relation between identical points on two reference surfaces or points on reference and projection surface.
	M2: 1 - only one 2 - two and more	Q2: How many cartographic map projections is it possible to use?	2	2	0.16	0.32	0.32	
	M3-4: 0 - no	Q3: Is it possible to set international cartographic projection?	1	1	0.16	0.16	0.16	
	1 - yes	Q4: Is it possible to set national cartographic projection?	1	1	0.16	0.16	0.16	In relation to user's country.
3	**G: Noncartographic map outline (max. 10 %)**							
	M: 0 - no 1 -yes	Q: Is it possible to set up map outline in the form anamorphous construction (schema) points, lines and areas?	0	0	0.10	0.00	0.00	X, Y coordinates of map face construction are not function of geographical coordinates but function of another non spatial functions (e.g. areas are directly proportional to number of inhabitants, distances are directly proportional shipping expenses etc.)
Total						**2.70**	**2.70**	
2. Reference system of map face					4.00			
1	**G: Standard of reference system (max. 10 %)**							
	M: 0 - no	Q: Is it possible to set up optionally international/national system (DATUMS) of map face?	1	1	0.10	0.10	0.10	**DATUM** - specific properties of reference system (geoid model, including coordinate, elevation, gravity/geodetic system and other characteristics)
	1 - yes							Parameter or set of parameters, which serve as reference or base to calculation of other parameters.
2	**G: Coordinate system (max. 40 %)**							
	M1: 0 - no	Q1: Is it possible to set up various reference coordinate system of map face?	1	1	0.10	0.10	0.10	Geography, rectangular, spatial, cartographic coordinate system.
	1 - yes							
	M2: 0 - 1	Q2: How many coordinate systems is it possible to set up?	1	1	0.10	0.10	0.10	
	1 - two and more							
	M3: 0 - no	Q3: Is it possible to set up national coordinate system?	1	1	0.10	0.10	0.10	In relation to user's country.
	1 - yes							
3	**G: Coordinate grid (max. 20 %)**							
	M1-2: 0 - no	Q1: Is it possible to set up coordinate grid of map face variously?	1	1	0.10	0.10	0.10	Geographical, cartographical
	1 - yes	Q2: Is it possible to set up auxiliary orientation grid of map face?	1	1	0.10	0.10	0.10	Helping (in kilometres, ...)
4	**G: Elevation system (max. 20 %)**							
	M1-2: 0 - no	Q1: Is it possible to set various reference elevation system of map face?	0	0	0.10	0.00	0.00	International and national.
	1 - yes	Q2: Is it possible to set national reference elevation system of map face?	0	0	0.10	0.00	0.00	
5	**G: Generation of graticule of map - nomenclature (max. 20 %)**							
	M1-2: 0 - no 1 - yes	Q1: Is it possible to generate graticule of map layout (nomenclature system) of international map in map outline?	1	1	0.10	0.10	0.10	**Nomenclature** - sign of map sheet or section in map series.
		Q2: Is it possible to generate graticule of map layout (nomenclature system) of national map in map outline?	1	1	0.10	0.10	0.10	**Map series** - sum of map sheets, which continuously cover area (country, Earth). Representation of that area is not possible in one map in that scale.
Total						**3.20**	**3.20**	

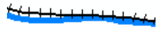
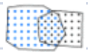
3. Transformation of map outline					**4.00**			
1	**G: Transformation of cartographic projection (max. 20 %)**							
	M: 0 - no	Q: Is it possible to transform cartographic projections each other?	1	1	0.20	0.20	0.20	
	1 - yes							
2	**G: Transformation of coordinate system (max. 20 %)**							
	M: 0 - no	Q: Is it possible to transform coordinate systems each other?	1	1	0.20	0.20	0.20	
	1 - yes							
3	**G: Transformation of coordinate grid (max. 10 %)**							
	M: 0 - no 1 -yes	Q: Is it possible to transform geographic/cartography/orientation auxiliary grids each other?	0	0	0.10	0.00	0.00	
4	**G: Analytical transformation (max. 20 %)**							
	M: 0 - no 1 -yes	Q: Is it possible to use direct (analytical) transformation based on cartographical projection equation?	1	0	0.20	0.20	0.00	**Cartographical projection equation** - mathematical conversion of point coordinates on reference bodies (ellipsoid, sphere) and surface
5	**G: Numeric transformation (max. 20 %)**							
	M1-4: 0 - no	Q1: Is it possible to use indirect numeric transformation?	1	1	0.05	0.05	0.05	**Indirect numerical transformation** - similar calculation on base of reference (identical) point coordinates in source and target system (surface)
	1 - yes	Q2: Is it possible to use indirect numeric linear transformation?	1	1	0.05	0.05	0.05	
		Q3: Is it possible to use affine (similar) first order polynomial transformation?	1	1	0.05	0.05	0.05	E.g. Helmert similarly conform transformation
		Q4: Is it possible to use second-order and third-order polynomial transformation?	1	0	0.05	0.05	0.00	
6	**G: Range of transformation (max. 10 %)**							
	M: 0 - no	Q: Is it possible to transform only a part of map face?	0	0	0.10	0.00	0.00	So called piecewise (segment) transformation of map face
	1 - yes							
Total						**3.20**	**2.20**	
4. Metadata about map construction					**2.00**			
1	**G: Standardisation of generation of metadata (max. 100 %)**							
	M1-2: 0 - no 1- yes	Q1: Is it possible to generate standard information about procedures, methods, sources and other properties of map construction?	1	1	0.50	0.50	0.50	Metainformation about: reference and coordinate system, reference body (surface), elevation system, time system, extent of map face, method of data collection, progress and errors of transformations, …
		Q2: Is it used metadata standard (ISO/CEN/other)?	1	1	0.50	0.50	0.50	ISO - worldwide, CEN - European, other - Open Source, national,…
Total						**2.00**	**2.00**	
5. Cartometry					**2.00**			Tools for measuring in maps
1	**G: Distortion (max. 10 %)**							
	M: 0 - no	Q: Is it possible to determine cartographic distortion in any point in map face?	0	0	0.10	0.00	0.00	
	1 - yes							
2	**G: Measure and construction tools (max. 40 %)**							
	M1-2: 0 - no	Q1: Is it possible to measure location, length, area and volume of map objects and symbols in map face?	1	1	0.20	0.20	0.20	By way of coordinates, distances, angels, parallel constructions
	1 - yes	Q2: Is it possible to construct variously location, length, area and volume of map objects/symbols in map face?	1	1	0.20	0.20	0.20	
3	**G: Geodetic tools (max. 25 %)**							
	M: 0 - no 1 - yes	Q: Is it possible to use geodetic progresses/tasks in construction and editing of map objects/symbols in map face?	1	0	0.25	0.25	0.00	Polar method, resection, forward intersection, stationing, measure, adjustment area, …
4	**G: Map face frame (max. 25 %)**							
	M: 0 - no	Q: Is it possible to generate map face frame automatically?	1	1	0.25	0.25	0.25	
	1 - yes							
Total						**1.80**	**1.30**	
TOTAL - A Map construction						**12.90**	**11.40**	

B Map symbols

P	GOAL	QUESTION	ArcGIS	QGIS	WEIGHT	SCORE ArcGIS	SCORE QGIS	EXPLANATORY NOTES
					35.00			Creation, using and location of map symbols in map face.
1. Pattern book					1.50			
1	**G: Availability of symbol types (max. 30 %)**							
	M1-3 : 0 - no	Q1: Is it possible to insert point symbol into the map?	1	1	0.15	0.15	0.15	
	1 - yes	Q2: Is it possible to insert line symbols into the map?	1	1	0.15	0.15	0.15	
		Q3: Is it possible to insert area symbol into the map?	1	1	0.15	0.15	0.15	
2	**G: Completeness of pattern book (max. 70 %)**							
	M1-5 : 0 - no	Q1: Can the user supplement the pattern book with new symbols?	1	1	0.15	0.15	0.15	
		Q2: Is raster editor of symbols available?	0	0	0.15	0.00	0.00	
		Q3: Is vector editor of symbols available?	1	1	0.30	0.30	0.30	
		Q4: Is it possible to edit predefined symbols by raster editor?	0	0	0.15	0.00	0.00	
		Q5: Is it possible to edit predefined symbols by vector editor?	1	1	0.30	0.30	0.30	
Total						**1.20**	**1.20**	
2. Point symbols					8.00			
1	**G: Pattern book of point symbols (max. 2,5 %)**							
	M: 0 - no 1 - yes	Q: Is it possible to select any point symbol from predefined pattern book?	1	1	0.20	0.20	0.20	
2	**G: Associativity of symbols (max. 35 %)**							
	M1-4: 0 - no	Q1: Does the pattern book contain non motivated point geometric convex symbols?	1	1	0.50	0.50	0.50	
	1 - yes	Q2: Does the pattern book contain non motivated point geometric non convex symbols?	1	1	0.50	0.50	0.50	
		Q3: Does the pattern book contain alphanumeric symbols (letters, names, numbers)?	1	1	0.50	0.50	0.50	Prague 752 A.3.b
		Q4: Does the pattern book contain motivated point symbols? (i.e. symbolic/pictogram/iconic/pictorial)?	1	1	1.30	1.30	1.30	Symbols with associations of shape, color and other properties, that symbolizes represented phenomenon or object. 
3	**G: Graphic variability of symbols (max. 25 %)**							
	M1-4: 0 - no	Q1: Is it possible to change color of point symbols?	1	1	0.50	0.50	0.50	
	1 - yes	Q2: Is it possible to set size of point symbols?	1	1	0.50	0.50	0.50	
		Q3: Is it possible to change color or raster fill of point symbols?	1	1	0.50	0.50	0.50	Fill (color, structure, texture, raster) - graphic elements with various shape, size, color, arrangement and orientation. Note: Examples of raster are at goal 4. Area symbols. 
		Q4: Is it possible to change angle of orientation of point symbols?	1	1	0.50	0.50	0.50	
4	**G: Attribute variability of symbols (max. 20 %)**							
	M1-2: 0 - no	Q1: Is it possible to change parameters of point symbols according value of attribute of represented phenomenon/object?	1	1	0.80	0.80	0.80	**Parameters: size, orientation, fill (color, raster), structure.**
	1 - yes	Q2: Is it possible to change gradually symbol parameters according statistic processing of attribute values of represented phenomenon/object?	1	1	0.80	0.80	0.80	Continuous or intervallic graduation. 
5	**G: Symbol morphography (max. 12,5 %)**							Assembling and disassembling of symbol to graphic elements and components.
	M1-4: 0 - no	Q1: Is it possible to disassemble a point symbol to elements?	1	1	0.25	0.25	0.25	
	1 - yes	Q2: Is it possible to assemble symbol from elements of others point symbols?	1	1	0.25	0.25	0.25	
		Q3: Is it possible to change location of relative point of a symbol?	1	1	0.25	0.25	0.25	
		Q4: Does any editor for creation of new point symbols exist?	1	1	0.25	0.25	0.25	Optional edit of symbol fill, outline.
6	**G: Dynamic of symbols (max. 5 %)**							
	M 1-2: 0 - no	Q1: Is it possible to animate point symbols?	0	0	0.20	0.00	0.00	Change of shape, color (hue, brightness, saturation), size, location, fill, orientation, disassembling and assembling of symbol, combination of various changes, another type of animation.
	1 - yes	Q2: Is it possible to animate point symbol according attribute data?	0	0	0.20	0.00	0.00	
Total						**7.60**	**7.60**	

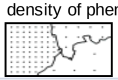
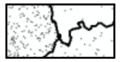
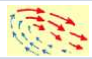
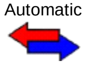
3. Line symbols					8.00			
1	**G: Pattern book of line symbols (max. 25 %)**							
	M1-7: 0 - no 1 - yes	Q1: Is it possible to select any line symbol from predefined pattern books?	1	1	0.10	0.10	0.10	Pattern books: number of lines (one-line and multi-line), color - achromatic, chromatic, color combine; line with fill - (without fill between lines), with color fill, with pattern.
		Q2: Does a pattern book contain mono-line symbols?	1	1	0.30	0.30	0.30	Continuous and discontinuous line, including patterned lines.
		Q3: Does a pattern book contain broken line?	1	1	0.30	0.30	0.30	Broken line (periodic and aperiodic): dotted, dashed, dash-and-dot line.
		Q4: Does a pattern book contain line with different thickness?	1	1	0.40	0.40	0.40	Different (various) thickness - continuously or intervallic graduation.
		Q5: Does a pattern book contain patterned lines?	1	1	0.30	0.30	0.30	Pattern: geometric or other symbols; direction, wavy line.
		Q6: Does a pattern book contain a band line?	1	1	0.30	0.30	0.30	Band line is used for boundary line.
		Q7: Does pattern book contain two and more line symbols and other variations?	1	1	0.30	0.30	0.30	Outline, filled with color, patterned fill, segmented, with protective surroundings, set up background and foreground of symbol, etc.
2	**G: Associativity of symbols (max. 10 %)**							
	M: 0 - no 1 - yes	Q: Does pattern book contain motivated line symbols?	1	1	0.80	0.80	0.80	**Symbols with association of shape, color and other properties, that symbolize represented phenomenon/object.**
3	**G: Graphic variability of symbols (max. 25%)**							
	M1-4: 0 - no	Q1: Is it possible to change thickness of line symbols?	1	1	0.50	0.50	0.50	
	1 - yes	Q2: Is it possible to change colour of line symbols?	1	1	0.50	0.50	0.50	Any use (construction) color tone, brightness, saturation, or to use color from the palette of colors.
		Q3: Is it possible to change filling of line symbols?	1	1	0.50	0.50	0.50	Fill (structure, texture, raster) - graphic elements with various shape, size, color, arrange and orientation.
		Q4: Is it possible to change orientation of line symbols?	1	1	0.50	0.50	0.50	
4	**G: Attribute variability of symbols (max. 20 %)**							
	M1-2: 0 - no 1- yes	Q1: Is it possible to change parameters of line symbols according to value of attributes of represented phenomenon/object?	1	1	0.80	0.80	0.80	Parameters: thickness, orientation, fill (color, raster), structure, length.
		Q2: Is it possible to graduate symbol parameters according statistic processing of attribute values of represented phenomenon/object?	1	1	0.80	0.80	0.80	Continuous or intervallic graduation.
5	**G: Symbol morphography (max. 15%)**							
	M1-5: 0 - no	Q1: Is it possible to disassemble line symbol to elements?	1	1	0.20	0.20	0.20	Assembling and disassembling of symbol to graphic elements and components.
	1 -yes	Q2: Is it possible to assemble symbol from elements of others point or line symbols?	1	1	0.40	0.40	0.40	
		Q3: Does editor of new line symbol exist?	1	1	0.30	0.30	0.30	
		Q4: Is it possible to set up indentation of line symbol?	1	1	0.20	0.20	0.20	E.g. from center line, from start of line. Both simple line and compound line; indent the first line from the second.
		Q5: Is it possible to set various ending of line symbol?	1	0	0.10	0.10	0.00	Arrow, space, rounding.
6	**G: Dynamic of symbols (max. 5%)**							
	M1-2: 0 - no 1 - yes	Q1: Is it possible to animate line symbols?	0	0	0.20	0.00	0.00	Change of shape, color (shade, brightness, saturation), size, location, fill, orientation, assembling and disassembling of symbol, ... combination of more type of change.
		Q2: Is it possible to animate line symbols according to attribute data?	0	0	0.20	0.00	0.00	
Total						7.60	7.50	

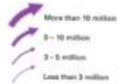
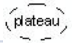
4. Area symbols					**8.00**			
1	**G: Pattern book of area symbols (max. 10 %)**							
	M1-3: 0 - no	Q1: Is it possible to select any area symbol from predefined pattern book?	1	1	0.10	0.10	0.10	
	1 - yes	Q2: Does a pattern book contain only simple area symbols?	1	1	0.30	0.30	0.30	One of this two types: 1. distinctly and unique demarcate area (by outline, color, pattern, point symbol) 2. indistinctly demarcate area, without filling or fill up area (by color, patter, point symbols). 
		Q3: Does a pattern book contain composite (compound) symbols?	1	1	0.40	0.40	0.40	Area with outline, with pattern, fill up, segmented, with protective surroundings. I.e. both first and second type mentioned above. 
2	**G: Associativity of symbols (max. 7,5 %)**							
	M: 0 - no 1 - yes	Q: Does a pattern book contain motivated area symbols?	1	1	0.60	0.60	0.60	Symbols with association of shape, color and other properties that symbolize represented phenomenon/object. 
3	**G: Graphic variability of symbols - outline of area (max. 20 %)**							
	M 1-4: 0 - no	Q1: Is it possible to change thickness of outline of area symbol?	1	1	0.40	0.40	0.40	
	1 - yes	Q2: Is it possible to change color of outline of area symbol?	1	1	0.40	0.40	0.40	
		Q3: Is it possible to change structure of outline of area symbol?	1	1	0.40	0.40	0.40	Structure - broken line, pattern line, multiple line, compound line.
		Q4: Is it possible to change line orientation of outline of area symbol?	1	1	0.40	0.40	0.40	Band line, oriented symbols.
4	**G: Graphic variability of symbols - fill of area (max. 30 %)**							
	M 1-6: 0 - no	Q1: Is it possible to change color of fill of area symbol?	1	1	0.40	0.40	0.40	
	1 -yes	Q2: Is it possible to set line structure of raster fill of area symbol?	1	1	0.40	0.40	0.40	
		Q3: Is it possible to set point structure of raster fill of area symbol?	1	1	0.40	0.40	0.40	
		Q4: Is it possible to set density of raster fill?	1	1	0.40	0.40	0.40	Distance between lines or vertical and horizontal spacing of point symbol. 
		Q5: Is it possible to set size of raster fill?	1	1	0.40	0.40	0.40	Thickness of lines or size of point symbol.
		Q6: Is it possible to set orientation of raster fill?	1	1	0.40	0.40	0.40	Orientation of lines or orientation of point symbols.
5	**G: Attribute variability of symbols (max. 20 %)**							
	M1-2: 0 - no 1 - yes	Q1: Is it possible to change the graphics of area symbols on the range of attribute values displayed the phenomenon / object?	1	1	0.80	0.80	0.80	
		Q2: Is it possible to change gradually (continuously or by intervals) parameters of a symbol on the basis of statistical processing of attribute values of a displayed phenomenon?	1	1	0.80	0.80	0.80	
6	**G: Symbol morphography (max. 7,5 %)**							
	M1-3: 0 - no	Q1: Is it possible to disassemble area symbol to elements?	1	1	0.20	0.20	0.20	Assembling and disassembling of symbol to graphic elements and components.
	1 - yes	Q2: Is it possible to assemble (combine) area symbol from other elements, from more area symbols?	1	1	0.20	0.20	0.20	
		Q3: Does editor for creation of new area symbols exist?	1	1	0.20	0.20	0.20	
7	**G: Dynamic of symbols (max. 5 %)**							
	M1-2: 0 - no 1 - yes	Q1: Is it possible to animate area symbols?	0	0	0.20	0.00	0.00	Change of shape, color (shade, brightness, saturation), size, location, fill, orientation, assembling and disassembling of symbol, ... combination of more type of change.
		Q2: Is it possible to animate area symbol according to attribute data?	0	0	0.20	0.00	0.00	
Total						**7.60**	**7.60**	

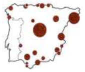
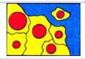
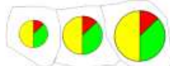
5. Localisation of map symbols					3.00			Composition of map symbols in map face.
1	**G: Localisation of symbol (max. 20%)**							
	M 1-2: 0 - no 1 - yes	Q1: Is it possible to localise symbol topographically?	1	1	0.15	0.15	0.15	Absolute topographic localisation of symbols on the basis of geographic or cartographic coordinates. Usage of localisation depends on the type of a symbol (primarily it is possible to localise point symbols).
		Q2: Is it possible to set up localisation of symbol according relative point or line?	1	1	0.15	0.15	0.15	Schematic localisation - to intend point, line.
2	**G: Symbol collision (max. 80%)**							
	M 1-9: 0 - no 1 - yes	Q1:Is it possible to find automatically collision of location of more symbols of the same type?	0	0	0.30	0.00	0.00	
		Q2: Is it possible to find automatically mutual collision of location of more types of symbols?	1	0	0.40	0.40	0.00	Point, line, area symbols.
		Q3: Is it possible to solve automatically mutual collision of localisation of various point symbols?	0	0	0.40	0.00	0.00	
		Q4: Is it possible to solve automatically mutual collision of localisation of varied line symbols?	0	0	0.40	0.00	0.00	
		Q5: Is it possible to solve automatically mutual collision of localisation of various area symbols?	0	0	0.30	0.00	0.00	
		Q6: Is it possible to solve automatically mutual collision of raster fill of overlapping area symbols?	0	0	0.20	0.00	0.00	
		Q7: Is it possible to solve automatically mutual collision of localisation of various symbols?	0	0	0.30	0.00	0.00	
		Q8: Is it possible to push automatically symbols aside when then scale is changed?	0	0	0.20	0.00	0.00	
		Q9: Is the number of symbols automatically reduced by selection, when the scale was changed?	0	0	0.20	0.00	0.00	
Total						**0.70**	**0.30**	

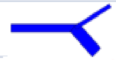
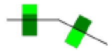
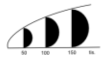
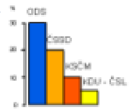
6. Color setting					6.00			
1	**G: Color palette (max. 30%)**							
	M1-5: 0 - no	Q1: Are there predefined color palettes?	1	1	0.50	0.50	0.50	
	1 - yes	Q2: Can you choose the color interactively from continuous color	1	1	0.50	0.50	0.50	
		Q3: Can you add custom colors to the color palette for reuse?	1	1	0.50	0.50	0.50	
		Q4: Can you name your own colors in the palette?	1	1	0.20	0.20	0.20	
		Q5: Are predefined color palettes from other manufacturers available?	0	1	0.10	0.00	0.10	PANTONE® etc.
2	**G: Color models (max. 15%)**							
	M1-3: 0 - no	Q1: Can you set the color code in RGB model?	1	1	0.30	0.30	0.30	Red, Green, Blue.
	1 - yes	Q2: Can you set the color code in HSV model?	1	1	0.30	0.30	0.30	Hue, Saturation, Value/Luminance (tone, saturation, brightness).
		Q3: Can you set the color code in CMYK model?	1	0	0.30	0.30	0.00	Cyan, Magenta, Yellow.
3	**G: Transparency (max. 5%)**							
	M1-2: 0 - no	Q1: Is it possible to set transparency color?	1	1	0.15	0.15	0.15	
	1 - yes	Q2: Is it possible to set transparency symbol or layer?	1	1	0.15	0.15	0.15	
4	**G: Setting "No color" (max. 10%)**							
	M: 0 - no 1 - yes	Q: Can you set the option "No color" for the symbol, fill, border, ...?	1	1	0.60	0.60	0.60	
5	**G: Color scales (schemes) (max. 40%)**							
	M1-5: 0 - no	Q1: Are there predefined qualitative (categorical) color schemes (various colors)?	1	1	0.50	0.50	0.50	
	1 - yes	Q2: Are there predefined sequential color schemes?	1	1	0.50	0.50	0.50	
		Q3: Are there predefined bipolar (diverging) color schemes?	1	1	0.50	0.50	0.50	
		Q4: Are there predefined color hypsometric scales (tint)?	1	1	0.50	0.50	0.50	
		Q5: Can you create your own color scales and save them for reuse?	1	1	0.40	0.40	0.40	
Total						**5.90**	**5.70**	
7. Metadata information about creation and structure of maps symbols					0.50			
	G: Metadata							
1	M1-2: 0 - no	Q1: Can you generate standardized information about methods, sources, composition, steps of creation and others properties of construction for map symbols?	0	0	0.25	0.00	0.00	E.g. type of map symbol, symbol identifier, (generating way of identification label of connection to attribute), characteristic of symbol (geometric, graphic, topological, attribute, time), distinguishing level of symbol (scale of maximum detail), annotation/labels of symbol, way and accuracy of localisation of symbol (accuracy of position and elevation,...), digitalisation method, steps for symbol creation, static and dynamic of symbol, cartographical methods for processing of symbol , etc.
	1 - yes	Q2: Is it international metadata standard (ISO/CEN/other)?	0	0	0.25	0.00	0.00	Other - national, Open Source, ...
Total							**0.00**	
TOTAL - B Map symbols					35.00	**30.60**	**29.90**	

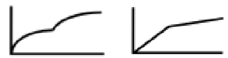
C Cartographic expression methods

P	GOAL	QUESTION	ANSWER ArcGIS	ANSWER QGIS	WEIGHT	SCORE ArcGIS	SCORE QGIS	EXPLANATORY NOTES
					35.00			
1. Basic methods					8.00			
1	**G: Method of point qualitative symbols (max. 15 %)**							
	M1-2: 0 - no	Q1: Can be used method of qualitative point symbols?	1	1	0.60	0.60	0.60	Creation and location point symbol from the statistical processing of the qualitative attribute values displayed objects / phenomena.
	1 - yes	Q2: Can be used method for schematic location of points?	1	0	0.60	0.60	0.00	Symbols are not localized topographically but schematically (guided). 
2	**G: Dotted method (max. 10 %)**							Labeling also as a method of dots, point density.
	M1-5: 0 - no	Q1: Can be used dotted method with topographical location of dots?	0	0	0.16	0.00	0.00	Creating and location of simple geometric symbols on the basis of statistical processing of qualitative-quantitative attribute values. Topographical location places the individual dots exactly according localization of the object / phenomenon.
	1 - yes	Q2: Can be used dotted method with regular placement of dots?	0	1	0.16	0.00	0.16	Regular (even, schematic) placement of dots in areas calculated automatically according density of phenomenon from attribute values. 
		Q3: Can be used various geometric symbols (circle, square, ...)?	1	1	0.16	0.16	0.16	
		Q4: Can be automatically adjust the size (weight) of dots according to the attribute value?	1	1	0.16	0.16	0.16	Size of dots express the quantity of phenomena.
		Q5: Is it possible to set irregular distribution of points in area?	1	0	0.16	0.16	0.00	Irregular distribution in schematic localisation of points. 
3	**G: Line qualitative method (max. 15 %)**							
	M1-2: 0 - no	Q1: Can be used method of qualitative topographical line symbols?	1	1	0.60	0.60	0.60	Creation and localisation of line symbols in map face according qualitative attribute value. Topographic shape express natural shape of object (river, road, boundary).
	1 - yes	Q2: Can be used method of qualitative schematic line symbols?	1	0	0.60	0.60	0.00	Schematic straight line, rounded lines, gradual lines.
4	**G: Line vector method (max. 15 %)**							Named also as a method of motion lines, direction lines, course lines.
	M1-8: 0 - no	Q1: Can be used method of **qualitative** vector line symbols?	1	1	0.30	0.30	0.30	Simple, consisting arrow, directional rose
	1 - yes	Q2: Can be used method of **quantitative** vector line symbols?	1	1	0.30	0.30	0.30	
		Q3: Can be used directional migration method?	0	1	0.10	0.00	0.10	Expresses the narrow direction of migration. 
		Q4: Can be used flow direction method?	0	0	0.10	0.00	0.00	
		Q5: Can be used method of directional mobility?	0	0	0.10	0.00	0.00	Areal directional symbols expressing wide-ranging mobility. 
		Q6: Can automatically adjust the quantity of vector diagram according the value attribute?	1	1	0.10	0.10	0.10	Automatic calculation of width, length and direction of area lines. 
		Q7: Can automatically graduate the vector diagram according the value attribute?	0	1	0.10	0.00	0.10	

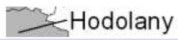
		Q8: Is automatically generated legend of vector symbols correct?	1	1	0.10	0.10	0.10	
5	**G: Area qualitative method (discrete Areal) (max. 15 %)**							Chorochromatic method, method of color tones
	M1-10: 0 - no	Q1: Can be used method of qualitative topographic area symbols?	1	1	0.12	0.12	0.12	Creation of discrete area symbols according qualitative attribute values.
	1 - yes	Q2: Can be used method of qualitative schematic area symbols?	1	0	0.12	0.12	0.00	Topographic boundaries are converted to straight lines.
		Q3: Is it possible to work with polygons that fully fill up map area?	1	1	0.12	0.12	0.12	
		Q4: Is it possible to work with areas that are isolated from one another?	1	1	0.12	0.12	0.12	
		Q5: Is it possible to work with areas that are overlap one another?	1	1	0.12	0.12	0.12	
		Q6: Is it possible to determine area by color?	1	1	0.12	0.12	0.12	
		Q7: Is it possible to determine area by raster?	1	1	0.12	0.12	0.12	
		Q8: Is it possible to determine area by label?	0	1	0.12	0.00	0.12	
		Q9: Is it possible to determine area by point symbol?	1	1	0.12	0.12	0.12	
		Q10: Is it possible to determine area by band line?	1	1	0.12	0.12	0.12	
6	**G: Area quantitative method (discrete Areal) (max. 15 %)**							Named also as **choropleth** method (cartogram method).
	M1-4: 0 - no	Q1: Can be used method of quantitative discrete areas?	1	1	0.30	0.30	0.30	Creation of discrete characters on the statistical processing of relative quantitative attribute values (e.g. population density / number of inhabitants per km2).
	1 - yes	Q2: Can be used simple color fill for area to express quantity?	1	0	0.30	0.30	0.00	Intensity of color expressed intensity of phenomenon.
		Q3: Can be used double intensive filling of area?	1	0	0.30	0.30	0.00	Intensity expressed e.g.. by hatch and by intensity of color. 
		Q4: Can be expressed quantity by raster, whose parameters are automatically calculated as the relative values of the attributes?	0	1	0.30	0.00	0.30	
7	**G: Area isoline method (continuous area) (max.15 %)**							Isoline method, isopleth method (USA), expression of continuous phenomenon.
	M1-3: 0 - no	Q1: Can be used isoline method only with isoline?	1	0	0.40	0.40	0.00	
	1 - yes	Q2: Can be used isoline method with fill-in isoline?	1	0	0.40	0.40	0.00	
		Q3: Is it possible generate isoline or isolayer from surface?	1	1	0.40	0.40	0.40	Automatic creation of isoline e.g.. thickened and supplementary contour line.
Total						**6.86**	**4.76**	

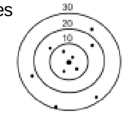
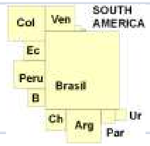
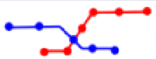
2. Diagram map (Cart diagrams)					8.00			Diagram methods
1	**G: Point diagram (max. 5 %)**							Viewing only a quantitative point of absolute values of attributes of objects / phenomena.
	M: 0 - no 1- yes	Q: Is it possible to create simple point diagram (one parameter) according attribute data of point object / phenomenon?	1	1	0.40	0.40	0.40	Point localisation  
2	**G: Areal diagram (max. 5 %)**							
	M: 0 - no 1- yes	Q: Can create simple areal diagram (one parameter) according attribute data of point object / phenomenon?	1	1	0.40	0.40	0.40	Areal localisation 
3	**G: Graduation of one-parameter diagram (max. 5 %)**							For point and areal diagrams (chart).
	M1-2: 0 - no	Q1: Can set the degree of size in intervals for one-parameter diagram?	1	1	0.20	0.20	0.20	Size (area) of diagram corresponds to a certain value according stepped scale.
	1 - yes	Q2: Can set the size of one-parameter diagram continuously/functionally (proportionally).	1	1	0.20	0.20	0.20	Size (area) of each diagram corresponds to the exact size of the value.
4	**G: Types of multi-parameter point and areal diagrams (max. 20 %)**							
	M1-7: 0 - no	Q1: Can create composite diagram?	0	0	0.23	0.00	0.00	Single simple diagram for every parameter relative to one point or are 
	1 - yes	Q2: Can create structural diagram?	1	1	0.23	0.23	0.23	One diagram with the same size expresses more parameters, part is expressed in % (also simple separation) 
		Q3: Can create totalizing (summative) diagram?	1	1	0.23	0.23	0.23	Expression of more parameters, size of diagram expresses absolute value of phenomenon. 
		Q4: Can create comparative diagram?	0	0	0.23	0.00	0.00	Comparative big square expresses average (future value etc.) in every points/areas. 
		Q5: Can create dynamic diagram?	0	0	0.23	0.00	0.00	Diagram express time evolution of one parameter. 
		Q6: Can localise a mutli-parameter diagram to point?	1	1	0.23	0.23	0.23	Point diagram.
		Q7: Can localise a mutli-parameter diagram to the area?	1	1	0.23	0.23	0.23	Areal diagram. 
5	**G: Geometry and properties of diagrams (max. 15 %)**							
	M1-5: 0 - no	Q1: Can create bar diagram?	1	1	0.24	0.24	0.24	
	1 - yes	Q2: Can be viewed on the diagram positive and negative values?	1	1	0.24	0.24	0.24	
		Q3: Can create figure diagram?	0	0	0.24	0.00	0.00	
		Q4: Can create diagram with vector (directional) symbols?	0	0	0.24	0.00	0.00	
		Q5: Can diagram express any number of values?	1	1	0.24	0.24	0.24	E.g.. Limit of parts is three parts.

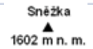
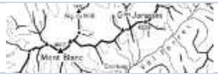
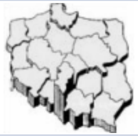
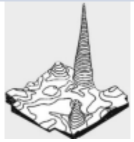
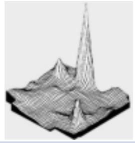
6	**G: Graduation of multi-parameter diagram (max. 5%)**							
	M1-2: 0 - no	Q1: Can set the degree of size in intervals for multi-parameter diagram?	1	0	0.20	0.20	0.00	Size (area) of diagram corresponds to a certain value according stepped scale.
	1 - yes	Q2: Can set the size of multi-parameter diagram continuously/functionally (proportionally).	1	1	0.20	0.20	0.20	Size (area) of each diagram corresponds to the exact size of the value.
7	**G: Localisation and properties of point and areal diagram (max. 5 %)**							
	M1-4: 0 - no	Q1: Can automatically avoid overlapping area of diagrams?	1	0	0.10	0.10	0.00	
	1 - yes	Q2: Is automatically created the leader line between diagram and the area / point to which it applies?	1	0	0.10	0.10	0.00	When the areal diagram not fit into the area, which belongs.
		Q3: Does diagram redraw automatically when the attribute values change?	1	1	0.10	0.10	0.10	
		Q4: Are the same types of diagrams available for point and area diagrams?	1	1	0.10	0.10	0.10	
8	**G: Line diagram (ribbon) (max. 30 %)**							
	M1-4: 0 - no	Q1: Is it possible to create simple line diagram according attribute data of line object / phenomenon?	0	0	0.60	0.00	0.00	Expression quantity by thickness of lines. 
	1 - yes	Q2: Is it possible to create a compound totalizing line diagram from more attributes?	0	1	0.60	0.00	0.60	Totalizing line diagram. 
		Q3: Is it possible to create a compound structural line diagram from more attributes?	0	0	0.60	0.00	0.00	The width of the ribbons are the same along the lines and it is 100 %. 
		Q4: Is it possible to create a separated totalizing line diagram?	0	0	0.60	0.00	0.00	
9	**G: Diagram scale in legend (max. 10 %)**							
	M1: 0 - no 1 - only diagram 2 - diagram and	Q1: Can be created a value scale in legend for the bar chart?	1	0	0.16	0.16	0.00	
	M2-4: 0 - no	Q2: Can be created a value scale in the legend for continuously graded pie diagram?	0	0	0.16	0.00	0.00	
	1 - yes	Q3: Can be created a value scale in the legend of the interval graded pie chart?	0	0	0.16	0.00	0.00	
		Q4: Are diagram value scale complete?	0	0	0.16	0.00	0.00	A description of the axes, a description of the scale of values, etc.  
Total					**7.84**	**3.79**	**3.83**	

3. Scale of values					**3.00**			Creation of various scales of quantitative value. Quantitative scale determines the parameters of the point, liner, area symbols (size, color, fill ..).
1	**G: Classification- Interval scale of values (max. 65 %)**							
	M1-7: 0 - no	Q1: Can be defined limits of interval of scale manually?	1	1	0.28	0.28	0.28	Any determination of the limits of the intervals by decision of the user.
	1 - yes	Q2: Can be automatically created a scale which is consists of the same intervals of values?	1	1	0.28	0.28	0.28	Constant (equal) intervals. 
		Q3: Limits of intervals are natural breaks?	1	1	0.28	0.28	0.28	Irregular scale - Natural breaks - Jenks. Grouping close values in one interval.
		Q4: Can be automatically created a scale by method of quantile?	1	1	0.28	0.28	0.28	Each interval contains the same number of elements. The method is suitable for linearly distributed data.
		Q5: Can be automatically created a interval scale according geometric progression?	0	0	0.28	0.00	0.00	Limits of intervals are geometric progression.
		Q6: Can be automatically created a scale by method of standard deviation?	1	1	0.28	0.28	0.28	The method is suitable for normal distribution of data.
		Q7: Can be defined a discrete interval scale, which contains a jump (hiatus) between the values?	1	1	0.28	0.28	0.28	Jump scale - with hiatus. 
2	**G: Functional scale of values (max. 25 %)**							Calculating intervals.
	M1-3: 0 - no 1- yes	Q1: Can be defined a continuous functional scale for determining the parameters of the symbol?	0	0	0.25	0.00	0.00	Functional scale - continuous. Graph of the dependence between a parameter of symbol on attribute: 
		Q2: Can be defined a functional discrete scale with jump?	0	0	0.25	0.00	0.00	Functional scale - with discontinuous hiatus. 
		Q3: Can be defined a discrete functional scale with change of function?	0	0	0.25	0.00	0.00	Functional scale - discrete scale with change of function. 
3	**G: Common characteristics of creation of scales (max. 10 %)**							
	M1-2: 0 - no 1- yes	Q1: Is there the graph of frequency values?	1	0	0.15	0.15	0.00	Graph (histogram) shows the distribution of values and allows to choose the most appropriate number of intervals and the method by user.
		Q2: Does every choropleth layer explanation/legend?	1	1	0.15	0.15	0.15	
Total						**1.97**	**1.82**	

4. Label					**10.00**			
1	**G: Manual creation of labels (max. 5 %)**							
	M: 0 - no 1 - yes	Q: Can be manually created the individual labels of feature?	1	1	0.50	0.50	0.50	By pointer (by mouse).
2	**G: Automatic creation of labels (max. 10 %)**							
	M: 0 - no 1 - yes	Q: Can be automatically created the labels of feature from attribute data?	1	1	1.00	1.00	1.00	
3	**G: Connection labels with attribute (max. 2 %)**							
	M: 0 - no 1 - yes	Q: Is content of labels automatically updated when the value of attribute changes?	1	1	0.20	0.20	0.20	
4	**G: Label from more attributes (max. 2 %)**							
	M: 0 - no 1 - yes	Q: Can be created label from more attributes?	1	1	0.20	0.20	0.20	
5	**G: Conditional selection of elements for labeling (max. 1 %)**							
	M: 0 - no 1 - yes	Q: Can be create condition for labeling selected features according attribute value?	1	1	0.10	0.10	0.10	
6	**G: Parameters of automatically created labels (max. 30 %)**							
	M1-9: 0 - no	Q1: Can be set font family?	1	1	0.33	0.33	0.33	Antigua, Medieval, Grotesque, Egyptiek, …
	1 - yes	Q2: Can be set font face?	1	1	0.33	0.33	0.33	Bolt, Semi bolt, Italic, …
		Q3: Can be set size of letters?	1	1	0.33	0.33	0.33	
		Q4: Can be set color of letters?	1	1	0.33	0.33	0.33	
		Q5: Can be set font spacing (spaces between letters)?	1	1	0.33	0.33	0.33	
		Q6: Can be set any slant of letters?	1	1	0.33	0.33	0.33	
		Q7: Can be set curvature of the label according a curve?	1	0	0.33	0.33	0.00	
		Q8: Can be set other parameters of fonts (underline, capital letters)?	1	1	0.33	0.33	0.33	
		Q9: Can be rotate label of a certain angle according to the attribute value?	1	0	0.33	0.33	0.00	
7	**G: Parameters of manually created labels (max. 14 %)**							
	M1-9: 0 - no	Q1: Can be set font family??	1	1	0.16	0.16	0.16	
	1 - yes	Q2: Can be set font face?	1	1	0.16	0.16	0.16	
		Q3: Can be set size of letters?	1	1	0.16	0.16	0.16	
		Q4: Can be set color of labels?	1	1	0.16	0.16	0.16	
		Q5: Can be set font spacing (spaces between letters)?	1	1	0.16	0.16	0.16	
		Q6: Can be set any slant of letters?	1	1	0.16	0.16	0.16	
		Q7: Can be set curvature of the label according a curve?	1	0	0.16	0.16	0.00	
		Q8: Can be set other parameters of fonts (underline, capital letters)?	1	1	0.16	0.16	0.16	
		Q9: Can be rotate label of a certain angle individually?	1	1	0.16	0.16	0.16	
8	**G: Symbol function of label (max. 4 %)**							
	M: 0 - no 1 - yes	Q: Can be set parameters of labels depending on attribute value (e.g. size of letter)?	0	1	0.40	0.00	0.40	
9	**G: Label of point feature (max. 5 %)**							
	M1-3: 0 - no	Q1: Can be optionally set the placement of label of point feature?	1	1	0.10	0.10	0.10	
	1 - yes	Q2: Can be set label directly to the point feature?	1	1	0.10	0.10	0.10	
		Q3: Are the placement of label predefined?	1	1	0.10	0.10	0.10	
	M4: 0 - only 1 place	Q4: How many predefined placements of label are?	2	2	0.10	0.20	0.20	
	1 - 1 to 4 placements							
	2 - 5 and more placements							

10	**G: Label of line feature (max. 5 %)**							
	M: 0 - no	Q1: Can be set optionally placement of line feature?	1	1	0.10	0.10	0.10	
	1 - yes	Q2: Can be set label on line?	1	1	0.10	0.10	0.10	
		Q3: Can be place label above line?	1	1	0.10	0.10	0.10	
		Q4: Can be place label under line?	1	1	0.10	0.10	0.10	
		Q5: Can be curved label of line according shape of line?	1	1	0.10	0.10	0.10	
11	**G: Label of area feature (max. 5 %)**							
	M1-3: 0 - no	Q1: Can be set optionally placement of area feature?	1	1	0.10	0.10	0.10	
	1 - yes	Q2: Can be put label completely into area?	1	1	0.10	0.10	0.10	
		Q3: Can be automatically create label in the main axis of polygon?	0	1	0.10	0.00	0.10	
	M4: 0 - only 1 place	Q4: How many predefined placements of label are?	2	2	0.10	0.20	0.20	
	1 - 1 to 4 placements							
	2 - 5 and more placements							
12	**G: Offset of label from feature (max. 2 %)**							
	M1-2: 0 - no	Q1: Can be set numeric value of offset of label from point feature?	1	1	0.10	0.10	0.10	
	1 - yes	Q2: Can be set numeric value of offset of label from line feature?	1	1	0.10	0.10	0.10	
13	**G: Masking of background under label (max. 4 %)**							
	M1-2: 0 - no	Q1: Can be create halo mask around label?	1	1	0.20	0.20	0.20	
	1 - yes	Q2: Can be create mask around label as polygonal shape?	0	1	0.20	0.00	0.20	
14	**G: Leader line (max. 1 %)**							
	M: 0 - no (manual drawing of leader line)	Q: Can be created leader line between feature and label?	0	0	0.10	0.00	0.00	
	1 - yes (automatic drawing)							
15	**G: Weight of label (max. 2 %)**							
	M: 0 - no	Q: Can be set the weight of label against other feature of map?	1	1	0.20	0.20	0.20	
	1 - between different labels of themselves							
	2 - between labels and geometry							
16	**G: Overlapping of labels (max. 2 %)**							
	M: 0 - no	Q: Can be automatically avoid overlapping of labels?	1	1	0.20	0.20	0.20	
	1 - yes							
17	**G: Conversion of labels to text (max. 2 %)**							
	M: 0 - no	Q: Can be convert labels to stand alone text?	1	0	0.20	0.20	0.00	Text is independent to attribute.
	1 - yes							
18	**G: Display of label depending on the map scale (max. 2 %)**							
	M: 0 - no	Q: Can be set displaying of labels only in specific map scales?	1	1	0.20	0.20	0.20	
	1 - yes							
19	**G: Label with hypertext (max. 1 %)**							
	M: 0 - no	Q: Can be connect label with hypertext?	0	0	0.10	0.00	0.00	
	1 - yes							
20	**G: Multi-line label (max. 1 %)**							
	M: 0 - no	Q: Can be create multi-line label?	1	1	0.10	0.10	0.10	
	1 - yes							
Total					**9.80**	**9.10**	**8.78**	

5. Specific methods					6.00			
1	**G: Cartograms methods (max. 20 %)**							Named also: geographic (cartographic) anamorphosis.
	M1-8: 0 - no	Q1:Can be create various anamorphosis schema (specific logical-formal schema) in map face ?	0	0	0.15	0.00	0.00	Automatic abstract change of exact topographic localisation according to the mathematical relations for the highlight quantitative phenomenon. An abstracted and simplified map the base of which is not true to scale (ASPRS at. al., 1994).
	1 - yes	Q2: Can be create automatic **radial** (circular) **geographical** anamorphosis?	0	0	0.15	0.00	0.00	Quantity is expressed by the distance from the center of concentric circles direction. Geographic radial anamorphosis expressed e.g. time as the distance to the center. 
		Q3: Can be create automatic **radial** (circular) mathematical anamorphosis?	0	0	0.15	0.00	0.00	Conversion of distance according to a mathematical formula, such as a logarithmic scale for highly concentric phenomena.
		Q4: Can be create automatic (nonradial) **general contiguous** anamorphosis?	0	0	0.15	0.00	0.00	Quantity phenomenon is expressed by the change of area. E.g.. population expressed by surface is anamorphosis. For continuous anamorphosis (contiguous cartograms) topology and adjacency of areas are maintained and there is a change in area and shape of boundaries. 
		Q5: Can be create automatic (nonradial) **general non-contiguous** anamorphosis?	0	0	0.15	0.00	0.00	The non-contiguous nonradial anamorphosis is maintained shape of region, but not maintained topology and connectivity of adjacent areas (there is either overlaps or spacing). 
		Q6: Can be create equivalent areal anamorphosis?	0	0	0.15	0.00	0.00	Equivalent areal anamorphosis preserves area and change the borders to simple geometric shapes. Demers variant. 
		Q7: Can be create Dorling cartogram?	0	0	0.15	0.00	0.00	
		Q8: Can be create axial anamorphosis?	0	0	0.15	0.00	0.00	Often used for transport links: buses, trams, metro (subway). 

2	**G: Georelief method (max. 40 %)**							
	M1-6: 0 - no	Q1: Can be represent georelief by peak elevation (spot height)?	1	0	0.40	0.40	0.00	
	1 - yes	Q2: Can be represent georelief by contours (isohyps)?	1	0	0.40	0.40	0.00	
		Q3: Can be represent georelief by line of skeleton of georelief?	1	0	0.40	0.40	0.00	
		Q4: Can be set represent georelief by color hypsometry?	1	1	0.40	0.40	0.40	
		Q5: Can be represent georelief by shading?	1	0	0.40	0.40	0.00	
		Q6: Can be represent georelief by hatching?	1	0	0.40	0.40	0.00	
3	**G: Satellite method (max. 10 %)**							
	M: 0 - no	Q: Can be insert in map face aerial and satellite photograph of remote sensing?	1	1	0.60	0.60	0.60	
	1 - yes							
4	**G: 3D – dimension method (max. 10 %)**							Block diagram method, cross profile method.
	M1-3: 0 - no 1 - yes	Q1: Can be display 3D symbol in map face?	1	0	0.20	0.20	0.00	Topographic or schematic placement. 
		Q2: Can be generate 3D isoline and block diagrams?	1	0	0.20	0.20	0.00	
		Q3: Can be generate 3D cross profile ?	1	0	0.20	0.20	0.00	
5	**G: Dynamic / animated method (max. 20 %)**							
	M: 0 - no	Q: Can be create dynamic / animated maps?	1	1	1.20	1.20	1.20	There exist tools for animation, for dynamic change of map face / map layer .
Total						**4.80**	**2.20**	
TOTAL - C Cartographic expression methods					**35.00**	**26.53**	**21.39**	

D Map syntax: stratigraphic, component and composition

P	GOAL	QUESTION	ANSWER ArcGIS	ANSWER QGIS	WEIGHT	SCORE ArcGIS	SCORE QGIS	EXPLANATORY NOTES
					15.00			
1. Overall design and layout of symbols in the map face					1.5			
1	**G: Editor of map face (max. 100 %)**							
	M1 - 7: 0 - no	Q1: Exist tools for editing/management of map face (management of content or layers)?	1	1	0.15	0.15	0.15	
	1 - yes	Q2: Can be cerate copy/replica of map face?	1	1	0.30	0.30	0.30	
		Q3: Can be fixed location of map face?	1	1	0.15	0.15	0.15	
		Q4: Can be fixed size of map face?	1	1	0.15	0.15	0.15	Adjustment of dimension of map face.
		Q5: Can be fixed scale of map face?	1	1	0.15	0.15	0.15	
		Q6: Can create cut-out box of map face?	1	1	0.30	0.30	0.30	Side overview map or detail map.
		Q7: Can be change dimension of map face (from 2D to 2,5D, 3D, 4D)?	0	0	0.30	0.00	0.00	
Total						**1.20**	**1.20**	
2. Map layers					3.0			
1	**G: Components of map (max. 20 %)**							Syntax of map: horizontal and vertical arrangement of content of map face.
	M: 0 - no 1 - yes	Q: Can change the content (syntactic components and elements) of map face in different ways?	1	1	0.60	0.60	0.60	**Syntactic element** - a set of objects/phenomena or their attributes in the map face marked with one symbol in the legend of the map. **Syntactic component** - the group of syntactic elements of map.
2	**G: Vertical stratigraphic of layers (max. 40 %)**							Vertical pile of individual map components of content - foreground and background of map, order of layers, layering of content of map field.
	M1 - 3: 0 - no	Q1: Can variously change vertical arrangement (of layers) in map face?	1	1	0.40	0.40	0.40	
	1 - yes	Q2: Can variously switch on or switch off displaying of layers in map	1	1	0.40	0.40	0.40	
		Q3: Can change content/elements of individual layers of map face depending on their vertical arrangement?	1	1	0.40	0.40	0.40	Possibility of changing the properties of symbols (groups of symbols, selected symbols) in one layer, depending on the vertical arrangement of layers.
3	**G: Components of layers (max. 40 %)**							Syntax of map, arrangement of content of map face.
	M1-3: 0 - no 1 - yes	Q1: Can variously change the content (components and elements) of one map layer?	1	1	0.40	0.40	0.40	Selecting only some elements of layer in the view of the map face.
		Q2: Can variously change the order of symbols in layer?	1	1	0.40	0.40	0.40	
		Q3: Can variously change parameters of selected symbols and groups of symbols in the layer?	1	1	0.40	0.40	0.40	More various symbols in one layer.
Total						**3.00**	**3.00**	
3. Composition - overall graphic arrangement of map					2.0			
1	**G: Composition options (max. 100%)**							
	M: 0 - no composition	Q1: How many types of graphic composition of map can be used?	2	2	0.40	0.80	0.80	Separate (one map), more sheet (map sheet from sheet lines), atlas, editorial, different composition.
	1 - one composition 2 - two and more							
	M2-4: 0 - no 1 - yes	Q2: Can be used a standardized composition?	1	1	0.40	0.40	0.40	Topographic composition (base topographic map) or composition with thematic content (road, geological, soil map).
		Q3: Can create and store template of composition for reusable?	1	1	0.40	0.40	0.40	
		Q4: Can be used cartographic expert methods (calculations) for compositing?	0	0	0.40	0.00	0.00	E.g. **Optimizing the deployment of elements** of composition, support information/**calculations of crowdedness of map** (graphic/symbol/information).
Total						**1.60**	**1.60**	

4. Basic composition elements - title and colophon					**0.5**			
1	**G: Title and colophon (max. 100%)**							
	M1-2: 0 - no	Q1: Can be created a title and subtitle maps?	1	1	0.25	0.25	0.25	
	1 - yes	Q2: Can be created colophon of map?	1	0	0.25	0.25	0.00	Map author, year, place of publication, … are in colophon (imprint).
Total						**0.50**	**0.25**	
5. Basic composition element - legend					**5.0**			
1	**G: Automation of legend creation (max. 40 %)**							
	M1-3: 0 - no	Q1: Can automatically generate a legend of map (map layer)?	1	1	0.67	0.67	0.67	
	1 - yes	Q2: Can the legend be segmented according vertical or horizontal composition (layers)?	0	1	0.67	0.00	0.67	
		Q3: Will automatically change the contents of the legend when change the content of the map and when change symbols?	1	1	0.67	0.67	0.67	Everything in the map (map cut-box) is also in legend.
2	**G: Cartographic rules of the legend (max. 60 %)**							
	M1-6: 0 - no	Q1: Can be arranged the symbols in the legend according importance and according logical association independently order of layers in the map face?	1	1	0.50	0.50	0.50	Requirement of arrange (order) of the legend.
	1 - yes	Q2: Can be create a hierarchy in a legend or divide to segments?	1	1	0.50	0.50	0.50	
		Q3: Is automatically generated legend complete?	1	1	0.50	0.50	0.50	
		Q4: Do symbols in the legend correspond to symbols in the map face (size, shape, ...)?	1	1	0.50	0.50	0.50	
		Q5: Can be created continuous graduated scale of areal symbols for choropleth map in the legend?	1	1	0.50	0.50	0.50	
		Q6: Can set the parameters of font in legend?	1	1	0.50	0.50	0.50	
Total						**4.33**	**5.00**	
6. Basic composition element - map scale					**1.0**			
1	**G: Graphic map scale (max. 70 %)**							
	M1: 0 - no (manual creation of scale) 1 - yes	Q1: Can automatically generate and put into map layout graphic scale?	1	1	0.10	0.10	0.10	
	M2: 0 - one shape 1 - 2 and more shape	Q2: How many shapes of graphic scale are?	1	1	0.10	0.10	0.10	
	M3: 0 - no 1 - yes	Q3: Can set length unit of graphic scale?	1	1	0.10	0.10	0.10	
	M4: 0 - no 1 - yes	Q4: Can set a subdivision of first part of graphic scale?	1	0	0.10	0.10	0.00	
	M5-7: 0 - no	Q5: Can set localization of label of graphic scale (under or above the scale)?	1	0	0.10	0.10	0.00	
	1 - yes	Q6: Is the scale automatically placed outside map face?	0	0	0.10	0.00	0.00	Expert location is outside the map face (not in the middle), in standard composition is placed standardly.
		Q7: Is there an automatic change of graphic scale when map face (cut, window) changes scale?	1	1	0.10	0.10	0.10	
2	**G: Numeric map scale (max. 30 %)**							
	M1-3: 0 - no	Q1: Can automatically generate and put into map layout numeric scale?	1	1	0.10	0.10	0.10	
	1 - yes	Q2: Can set parameters (size) of font of numeric scale?	1	1	0.10	0.10	0.10	
		Q3: Is there an automatic change of numeric scale when map face (cut, window) changes scale?	1	1	0.10	0.10	0.10	
Total						**0.9**	**0.7**	

7. Additional composition elements					2.0			
1 G: North arrow (max. 20 %)								
	M1-3: 0 - no	Q1: Can insert the north arrow in layout of the map?	1	1	0.10	0.10	0.10	**North arrow** is a graphical expression of orientation of map to the North (South,..).
	1 - yes	Q2: Can rotate symbol of north arrow?	1	1	0.10	0.10	0.10	
		Q3: Cab change size of symbol of north arrow?	1	1	0.10	0.10	0.10	
	M4: 0 - one	Q4: How many symbols of north arrow are?	1	0	0.10	0.10	0.00	
	1 - two and more							
2 G: Additional composition elements (max. 80 %)								
	M 1-6: 0 - no	Q1: Can create a text as the additional composition element?	1	1	0.27	0.27	0.27	
	1 - yes	Q2: Can create a table the additional composition element?	1	1	0.27	0.27	0.27	
		Q3: Can create a picture, a photograph, a logo as the additional composition elements?	1	1	0.27	0.27	0.27	
		Q4: Can create a graph, a diagram, a profile as the additional composition element?	1	0	0.27	0.27	0.00	
		Q5: Can insert side map?	1	1	0.27	0.27	0.27	
		Q6: Can insert multimedia elements?	1	1	0.27	0.27	0.27	
Total						**2.00**	**1.63**	
TOTAL - D Map syntax					**15.00**	**13.53**	**13.38**	

Testing Schema

Goal *"What is the degree of ... of ArcGIS/QGIS software?"*	**Metric**	**Question**	**ArcGIS**	**QGIS**	**Weight**	**ArcGIS**	**QGIS**
Functionality							
Suitability	0=no, 0.5= partly, 1=yes	Is there a suitable tool for the conduction of the task/analysis available?	1	1	44.00	44.00	44.00
Accuracy	0=no, 1=yes	Does the tool/algorithm deliver a correct result?	1	1	44.00	44.00	44.00
Interoperability	0=no, 1=yes	Can resources of an external software be used?	1	1	4.02	4.02	4.02
Security	0=no, 1=yes	*Is the data save from unauthorized access?*	1	1	0.00	0.00	0.00
Compliance	0=no, 1=yes	Are the input/output data formats standard formats?	1	1	7.97	7.97	7.97
					100.00	**100.00**	**100.00**
Reliability							
Maturity	0=no, 1=yes	Can the task/algorithm be performed completely in the first try?	1	1	42.15	42.15	42.15
	0=no, 1=yes or no adaptions	Can the task/algorithm be performed completely after cetain adaptions?	1	1	22.21	22.21	22.21
	0= ≥1, 1=0	Number of defects during the application of a task/algorithm	1	1	2.36	2.36	2.36
	0= ≥1, 1=0	Number of crashes during the application of a task/algorithm	1	1	5.67	5.67	5.67
	0=no, 1=yes	No restart of the software was required	1	1	2.36	2.36	2.36
	0=no, 1=yes	No restart of the hardware was required	1	1	5.67	5.67	5.67
	0=no, 1=yes	No new file had to be generated	1	1	2.36	2.36	2.36
	0=no, 1=yes	No new geodatabase had to be generated	1	1	2.36	2.36	2.36
	0=no, 1=yes	The data quality did not have to be adopted	1	1	2.36	2.36	2.36
Fault Tolerance	0=no, 1=yes or no infringement	Can the algorithm be performed despite the infringement of the specified input or ouput name (syntax)?	1	1	12.50	12.50	12.50
Recoverability	*0=no, 1=yes*	*Is the data saved during a software crash?*	0.00	0.00	0.00	0.00	0.00
					100.00	**100.00**	**100.00**

Usability							
Understandability	0=no, 1=yes	Could the required tools be identified without consulting the help?	1	1	2.16	2.16	2.16
	0=> 2, 1= ≤2	How many menu sublevels are needed to get to the tool?	1	1	0.38	0.38	0.38
	0=no, 1=yes	Can the tool be found with the help of a search function?	1	1	0.38	0.38	0.38
	0=no, 1=yes	Could the required tools be identified without consulting the internet?	1	1	4.28	4.28	4.28
Learnability	0=no, 1=yes	Is the documentation available in German language?	1	1	3.96	3.96	3.96
	0=no, 1=yes	Are there default settings/Can the tool be used without adaptions?	1	1	1.84	1.84	1.84
	0=no, 1=yes	Is there documentation for the specific tool available in the official help?	1	1	16.54	16.54	16.54
	0=no, 1=yes	Is there a help window intergrated in the tool to explain the tools' usage/ range of the settings?	1	1	10.97	10.97	10.97
	0=no, 1=yes	Can the help window be viewed at the same time as the settings?	1	1	1.31	1.31	1.31
	0=no, 1=yes or no algorithm	Are the scientific principles of the algorithm and settings explained?	1	1	9.66	9.66	9.66
	0=no, 1=yes or no error messages	Do error message hold an explanation for the nature of the error?	1	1	10.97	10.97	10.97
	0=no, 1=yes	Is there documentation for the specific tool available in the internet?	1	1	9.66	9.66	9.66
Operability	0=> 2, 1= ≤2	How many menu sublevels are needed to get to the tool?	1	1	5.01	5.01	5.01
	0=no, 1=yes	Does the program use unique symbols for the tool's GUI?	1	1	1.80	1.80	1.80
	0=no, 1=yes	Are the graphic design elements [colour, size, font, fill, form, direction, transparency] used coherently within all levels of the applied tool?	1	1	1.80	1.80	1.80
	0=no, 1=yes	Are there no unexpected responses?	1	1	1.80	1.80	1.80
	0=no, 1=yes	Does the tool give visual feedback during the [calculation] process?	1	1	1.80	1.80	1.80
	0=no, 1=yes	Can output be overwritten?	1	1	5.01	5.01	5.01
	0=no, 1=yes	Can the action be revoked?	1	1	4.82	4.82	4.82
	0=no, 1=yes or new layer created	If a new layer is created, can it automatically be added to the TOC?	1	1	5.01	5.01	5.01
	0=no, 1=yes	Are plugins/extensions/toolbars already activated?	1	1	0.86	0.86	0.86
					100.00	**100.00**	**100.00**

Efficiency							
Resources	0=no, 1=yes	Are plugins/extensions/toolbar already activated?	1	1	1.58	1.58	1.58
	0= twice as many 0.5=more, 1 = less or equal [than/to the competitor]	How many tools have to be used to fulfil the task?	1	1	6.55	6.55	6.55
	0=no, 1=yes	Can the task be fulfilled without the use of other programs?	1	1	3.23	3.23	3.23
	0=no, 1=yes	Are there are no Python programming skills required?	1	1	12.82	12.82	12.82
	0=no, 1=yes	Is there no internet connection required?	1	1	0.83	0.83	0.83
Speed/Time	0=no, 1=yes	Are there default settings/Can the tool be used without adaptions?	1	1	4.15	4.15	4.15
	0= twice as many 0.5=more, 1 = less or equal [than/to the competitor]	Number of steps to perform a specific analysis	1	1	8.85	8.85	8.85
	0= twice as slow or slower 0,5= slower 1= equal or faster	Processing time for the application of an algorithm/tool	1	1	42.38	42.38	42.38
	0=no, 1=yes	Is there a possibility to automate the process without programming?	1	1	19.65	19.65	19.65
					100	**100**	**100**

Suitability for Solar Analysis

Goal *"What is the degree of ... of ArcGIS/QGIS ...?"*	**Metric**	**Question**	**ArcGIS**	**QGIS**	**Weight**	**ArcGIS**	**QGIS**
Functionality		Is there a tool to caluclate the solar radiation ...					
Suitability	0=no, 1=yes	... for a set area for a certain day of the year?	1	1	3.30	3.30	3.30
	0=no, 1=yes	... for a set area for a certain period of the year?	1	0	3.30	3.30	0.00
	0=no, 1=yes	... for a set area for a certain time period on one day?	1	1	3.30	3.30	3.30
		... for a set area for certain intervals a day?	1	1	3.30	3.30	3.30
	0=no, 1=yes	... for a set area for the whole year with monthly intervals?	1	0	3.30	3.30	0.00
	0=no, 1=yes	Is it possible to set the resolution of the output raster?	1	1	1.10	1.10	1.10
	0=no, 1=yes	Is is possible to set a Z factor?	1	1	1.10	1.10	1.10
	0=no, 1=yes	It it possible to include the shadowing effect of terrain?	0	1	1.10	0.00	1.10
	0=no, 1=yes	Is it possible to input a slope raster with declination of solar panels?	0	1	1.10	0.00	1.10
	0=no, 1=yes	Is it possible to include a extra raster for aspect?	0	1	1.10	0.00	1.10
	0=no, 1=yes	It is possible to set the latitude?	1	1	1.38	1.38	1.38
	0=no, 1=yes	It is possible to set the longitude?	0	1	1.38	0.00	1.38
	0=no, 1=yes	Is it possible to set the azimuth directions?	1	1	1.38	1.38	1.38
	0 = less or equal, 1 = equal or more	How many radiation parameters can be set?	1	1	1.38	1.38	1.38
	0=no, 1=yes	Is there an output raster for direct radiation?	1	1	3.30	3.30	3.30
	0=no, 1=yes	Is there an output raster for diffuse radiation?	1	1	3.30	3.30	3.30
	0=no, 1=yes	Is there an output raster for the solar radiation duration?	1	1	3.30	3.30	3.30
	0=no, 1=yes	Is there an output raster for ground reflected radiation?	0	1	3.30	0.00	3.30
	0=no, 1=yes	Is there an output raster for total radiation?	1	1	3.30	3.30	3.30

Suitability for Network Analysis

Goal *"What is the degree of … of ArcGIS/QGIS*	**Metric**	**Question**	**ArcGIS**	**QGIS**	**Weight**	**ArcGIS**	**QGIS**
Functionality							
Suitability	0=no, 1=yes	Is it possible to determine the shortest path based on distance?	1	1	10.63	10.63	10.63
	0=no, 1=yes	Is it possible to determine the shortest path based on speed?	1	1	10.63	10.63	10.63
	0=no, 1=yes	Is it possible to build a network consisting of several layers?	1	0	4.38	4.38	0.00
	0=no, 1=yes	Can the topology tolerance be set?		1	1.66	0.00	1.66
	0=no, 1=yes	Can stops be included in the analysis?	1	0	4.38	4.38	0.00
	0=no, 1=yes	Can one-way roads be considered?	1	1	4.38	4.38	4.38
	0=no, 1=yes	Can different speeds be considered depending on the moving direction?	1	0	1.66	1.66	0.00
	0=no, 1=yes	Is it possible to include hierarchies?	1	0	2.67	2.67	0.00
	0=no, 1=yes	Can the calculated route be exported as a shapefile containing a feature for each section?	0	1	3.63	0.00	3.63

Suitability for Buffer

Goal *"What is the degree of … of ArcGIS/QGIS*	**Metric**	**Question**	**ArcGIS**	**QGIS**	**Weight**	**ArcGIS**	**QGIS**
Functionality							
Suitability	0=no, 1=yes	Buffer by distance	1	1	24.62	24.62	24.62
	0=no, 1=yes	Buffer by attribute	1	1	10.98	10.98	10.98
	0=no, 1=yes	Multiple ring buffer	1	0	4.20	4.20	0.00
	0=no, 1=yes	Buffer by attribute including scale	0	1	4.20	0.00	4.20

Suitability for Time Slider Analysis

Goal *“What is the degree of … of ArcGIS/QGIS*	**Metric**	**Question**	**ArcGIS**	**QGIS**	**Weight**	**ArcGIS**	**QGIS**
Functionality							
Suitability	0=no, 1=yes	Is it possible to create time enabled vector layer?	1	1	18.86	18.86	18.86
		Can several layer be included in the animation?	0	1	6.29	0.00	6.29
	0=no, 1=yes	Is it possible to set the time frame size?	1	1	0.79	0.79	0.79
	0=no, 1=yes	Is is possible to regulate the speed?	1	1	0.79	0.79	0.79
	0=no, 1=yes	Is it possible to fast forward and rewind?	1	1	0.79	0.79	0.79
	0=no, 1=yes	Can a starting point and ending point be set?	1	1	0.79	0.79	0.79
	0=no, 1=yes	Is it possible to set an offset?	1	1	0.79	0.79	0.79
	0=no, 1=yes	Is it possible to loop the animation?	1	1	0.79	0.79	0.79
	0=no, 1=yes	Is it possible to play the animation backwards?	1	1	0.79	0.79	0.79
	0=no, 1=yes	Can area chart and pie chart be represented at the same time?	0	1	6.29	0.00	6.29
	0=no, 1=yes	Ist it possible to set a time zone?	1	0	0.79	0.79	0.00
	0=no, 1=yes	Can the viedeo be exported correctly?	0	0	6.29	0.00	0.00

Suitability for Visibility Analysis

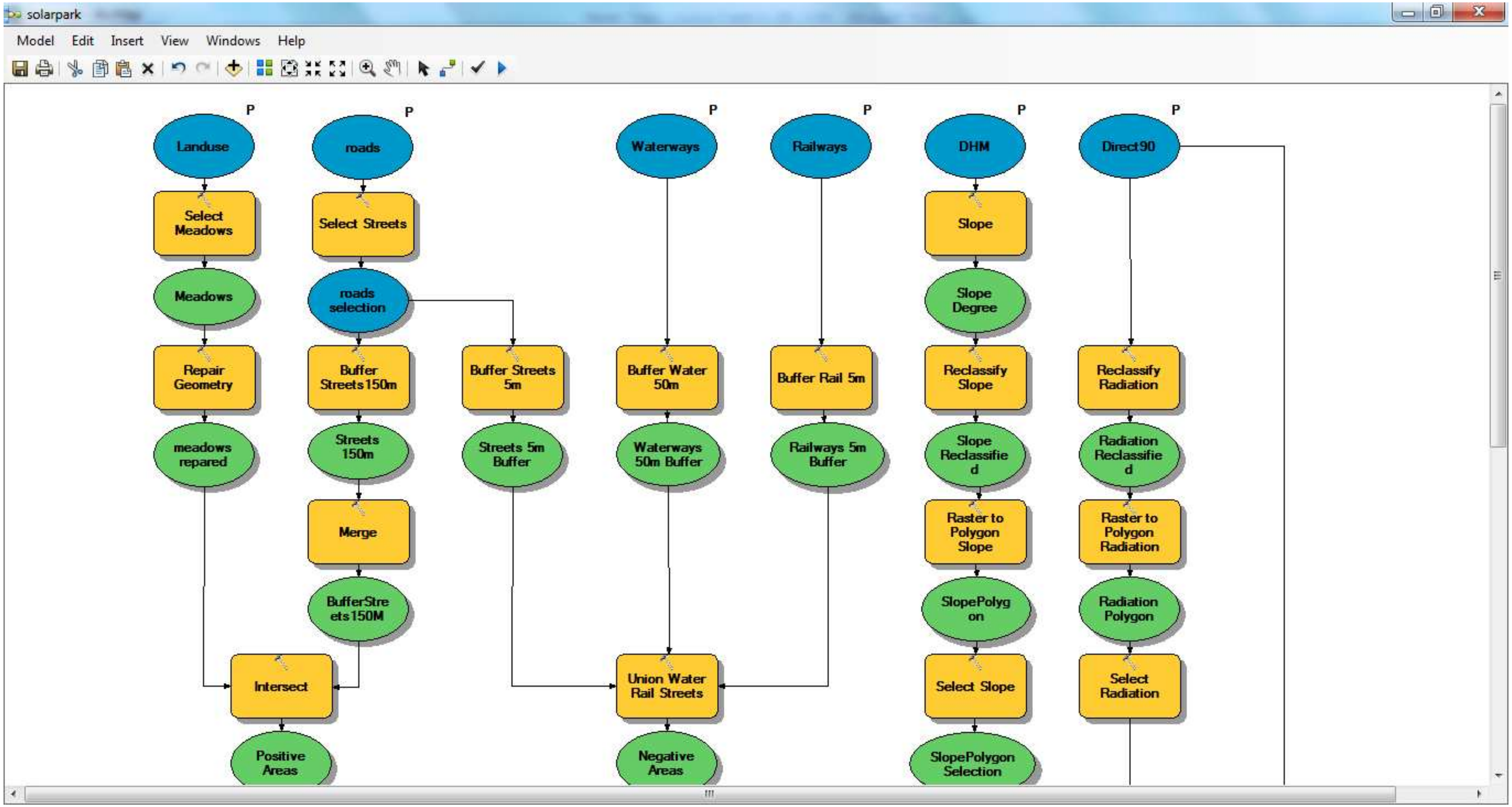
Goal *"What is the degree of … of ArcGIS/QGIS*	**Metric**	**Question**	**ArcGIS**	**QGIS**	**Weight**	**ArcGIS**	**QGIS**
Functionality							
Suitability	0=no, 1=yes	Can the visibility of a point be calculated?	1	1	18.62	18.62	18.62
	0=no, 1=yes	Can the height of the point be set?	1	1	8.19	8.19	8.19
	0=no, 1=yes	Can the height of the observer be set?	1	0	8.19	8.19	0.00
	0=no, 1=yes	Can the view range be set?	1	0	3.00	3.00	0.00
	0=no, 1=yes	Can the view direction be set?	1	0	3.00	3.00	0.00
	0=no, 1=yes	Can the vertical view angle be set?	1	0	3.00	3.00	0.00

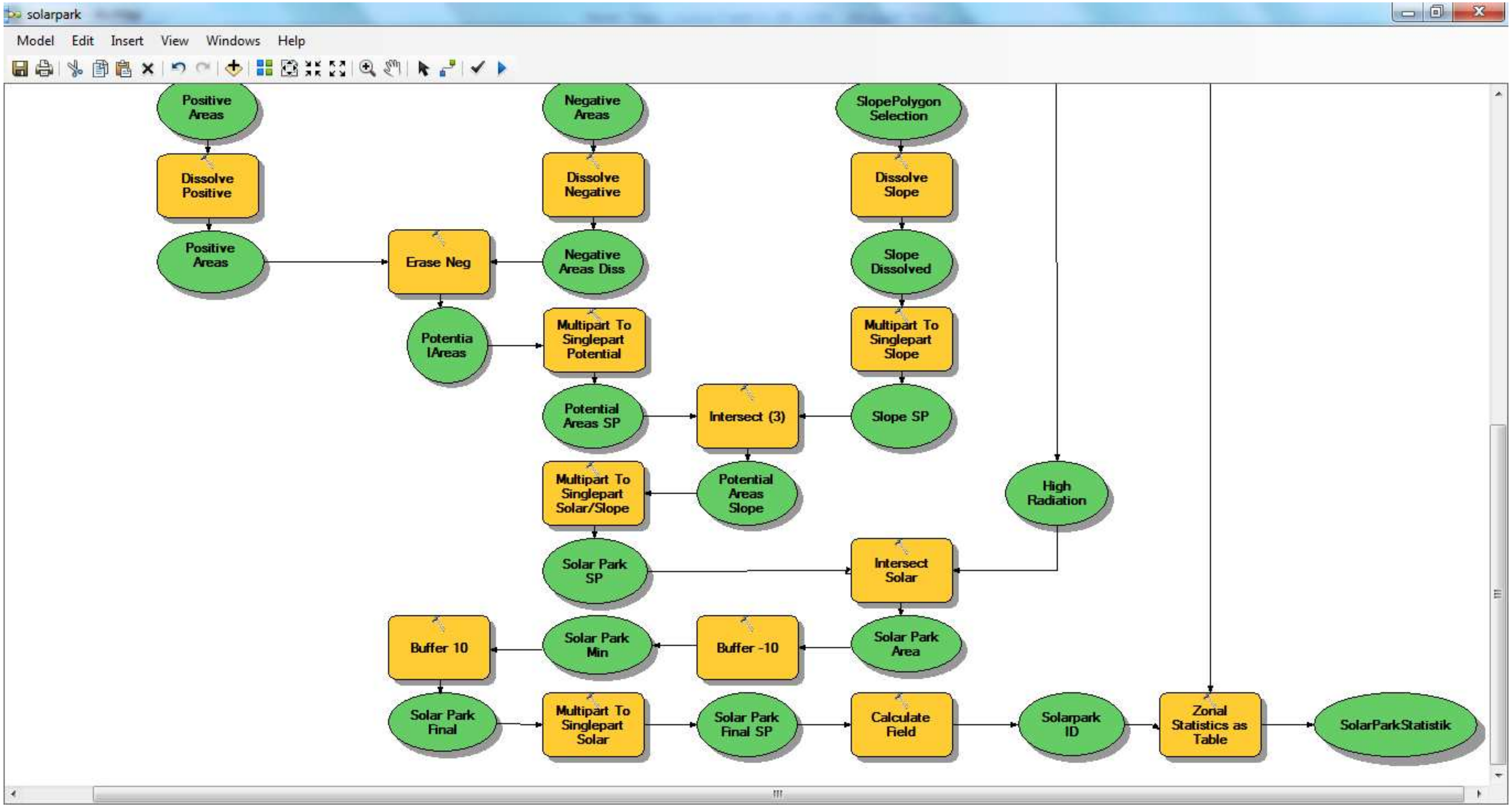
Suitability for Georeferencing

"What is the degree of … of ArcGIS/QGIS							
Functionality		Is it possible to georeference raster data base on a geographical coordinates?	1.00	1.00	11.8	11.85	11.85
Suitability	0=no, 1=yes	Is it possible to georeference raster data base on a georeferenced dataset?	1.00	1.00	11.8	11.85	11.85
	0=no, 1=yes	Can the Ground Control Points be saved?	1.00	1.00	4.9	4.88	4.88
	0=no, 1=yes	Can Ground Control Points be edited?	1.00	1.00	1.9	1.89	1.89
	0=no, 1=yes	It is possible to choose between different transformation types?	1.00	1.00	1.9	1.89	1.89
	0=no, 1=yes	It is possible to choose between different resampling methods?	1.00	1.00	1.9	1.89	1.89
	0=no, 1=yes	Can the referencing view and the map view operate symultaneously?	0.00	1.00	4.9	0.00	4.88

Models

Solar Search ArcGIS




solarpark
Model
Edit
Insert
View
Windows
Help
Positive Areas
Negative Areas
SlopePolygon Selection
Dissolve Positive
Dissolve Negative
Dissolve Slope
Positive Areas
Erase Neg
Negative Areas Diss
Slope Dissolved
Potentia lAreas
Multipart To Singlepart Potential
Multipart To Singlepart Slope
Potential Areas SP
Intersect (3)
Slope SP
Multipart To Singlepart Solar/Slope
Potential Areas Slope
High Radiation
Solar Park SP
Intersect Solar
Buffer 10
Solar Park Min
Buffer -10
Solar Park Area
Solar Park Final
Multipart To Singlepart Solar
Solar Park Final SP
Calculate Field
Solarpark ID
Zonal Statistics as Table
SolarParkStatistik

Lebenslauf

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Ich versichere:

- dass ich die Masterarbeit selbstständig verfasst, andere als die angegebenen Quellen und Hilfsmittel nicht benutzt und mich auch sonst keiner unerlaubten Hilfe bedient habe.
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- dass diese Arbeit mit der vom Begutachter beurteilten Arbeit übereinstimmt.

Datum: Wien, 18.12.2014 Corinna Friedrich