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QGIS A CONSTANTLY GROWING FREE AND OPEN-SOURCE GEOSPATIAL SOFTWARE CONTRIBUTING TO SCIENTIFIC DEVELOPMENT

MARCELA ROSAS-CHAVOYA[1], JOSÉ LUIS GALLARDO-SALAZAR[2]*, PABLITO MARCELO LÓPEZ-SERRANO[3], PEDRO CAMILO ALCÁNTARA-CONCEPCIÓN[4], ANA KAREN LEÓN-MIRANDA[5]

[1]Programa Institucional de Doctorado en Ciencias Agropecuarias y Forestales, Universidad Juárez del Estado de Durango, México.

[2]Facultad de Ciencias Forestales. Universidad Juárez del Estado de Durango, México.

[3]Instituto de Silvicultura e Industria de la Madera. Universidad Juárez del Estado de Durango, México.

[4]Dep. de Ingeniería Geomática e Hidráulica, División de Ingenierías. Universidad de Guanajuato, México.

[5]Copter Log Services GmbH, Klagenfurt am Wörthersee, Austria.

ABSTRACT. QGIS is the most popular free geospatial software in the world. QGIS belongs to the Open-Source Geospatial Foundation (OSGeo). Among the main strengths of this Geographic Information Systems are: the incorporation of tools via plugins, and a community of users and developers in constant growth. Despite the importance on the use of QGIS on the scientific community, to date there are no systematic studies indicating how the acceptance of this software has evolved through time. Therefore, the objective of this research was to characterize the scientific production and extent where QGIS has been used as their main geospatial tool. We conducted a bibliometric analysis of documents published in Scopus from 2005 to 2020 (931 manuscripts). The annual rate of publications increase was 40.3%. We found strong and positive correlations regarding the number of contributing code programmers ($r=0.66$, $p<0.005$); and the total income of the QGIS project ($r=0.88$, $p<0.001$). Seventy-two percent of the publications were included in six fields of study, being Earth and Planetary Sciences the most representative. Italy was the country with larger scientific production, while the USA was the most influential country (being the first, regarding the number of citations). In terms of the countries, the larger number of papers found were from Portugal, Italy, Brazil, and France. The International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences - ISPRS Archives stands among journals with the largest number of publications (47). In terms of collaborative networks among countries, we found strong links between authors from Germany, Switzerland, Greece, and Spain. Author network analysis showed three solid networks in different fields of study. We observed a favorable trend in the acceptance of QGIS across the world and a widespread development of collaborative networks. The present paper allowed increase the knowledge of geographic information systems, especially the development of scientific production using QGIS.

QGIS un software libre geospacial en constantemente crecimiento que contribuye al desarrollo científico

RESUMEN. QGIS es el software libre geoespacial más popular del mundo perteneciente a la Open Source Geospatial Foundation (OSGeo). Entre sus principales fortalezas se encuentran: la incorporación de herramientas vía plugins, y una comunidad de usuarios y desarrolladores en constante crecimiento. A pesar de la importancia que tiene el uso de QGIS en la comunidad científica, a la fecha no existen estudios sistemáticos que indiquen cómo ha evolucionado la

aceptación de este software a través del tiempo. Por lo tanto, el objetivo de esta investigación fue caracterizar la producción científica y la magnitud en la que QGIS se ha utilizado como principal herramienta geoespacial. Realizamos un análisis bibliométrico de los documentos publicados en Scopus de 2005 a 2020 (931 manuscritos). La tasa anual de incremento de publicaciones fue del 40,3%. Encontramos correlaciones fuertes y positivas con respecto al número de desarrolladores de código (r = 0,66, p <0,005); y los ingresos totales del proyecto QGIS (r = 0.88, p <0.001). El setenta y dos por ciento de las publicaciones se incluyeron en seis campos de estudio, siendo las Ciencias de la Tierra y Planetarias la más representativa. Italia fue el país con mayor producción científica, mientras que Estados Unidos fue el país más influyente (el primer lugar en número de citas). En cuanto a los países, el mayor número de artículos encontrados fueron de Portugal, Italia, Brasil y Francia. La International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences - ISPRS Archives se encuentra entre las revistas con más publicaciones (47). En términos de redes de colaboración entre países, encontramos fuertes vínculos entre autores de Alemania, Suiza, Grecia y España. El análisis de redes de colaboración entre autores identificó tres redes sólidas en diferentes campos de estudio. Observamos una tendencia favorable en la aceptación de QGIS en todo el mundo y un desarrollo generalizado de redes colaborativas. El presente trabajo permitió incrementar el conocimiento de los sistemas de información geográfica, especialmente el desarrollo de la producción científica utilizando QGIS.

Key words: Open-source software, QGIS, collaborative network, geospatial science, scientific contributions.

Palabras clave: software libre y de código abierto, QGIS, redes de colaboración, ciencias geoespaciales, contribuciones científicas.

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*Corresponding author: José Luis Gallardo-Salazar, Facultad de Ciencias Forestales, Universidad Juárez del Estado de Durango, Durango 34239, México. E-mail address: 1107805@alumnos.ujed.mx

1. Introduction

Free software allows us to know and adapt its source code to the needs of each user and gives the freedom to reproduce and distribute copies for the benefit of society (Stallman, 2015). Science is closely related with the Free Software concept. The fact that one of the most important aspects of science is reproducibility, a feature which allows anyone to test data, hypothesis, and methods, makes free software an ideal framework for the scientific work. In this context, the use of free software has been consolidated in our societies in a gradual and constant way (Robles *et al.*, 2019). Consequently, in the last decade, this philosophy has been further developed and permeated all scientific fields, including the geospatial sciences (Brovelli *et al.*, 2017; Coetzee *et al.*, 2020; Conrad *et al.*, 2015; Minghini *et al.*, 2020; Neteler *et al.*, 2012).

Free software focused on geospatial sciences had already a tradition on science right from the beginning of the free software, but it did not have an impact on geosciences until several individual projects gathered and decided to integrate a unique community. The creation and evolution of these projects is based on crowdsourcing, which is supported by large communities (project leaders, users, developers, translators, educational and research institutions, etc.) from all over the world (Sarı *et al.*, 2019; See *et al.*, 2016). Over the years, this resulted in interesting but dispersed software packages with lack of direction. It was not until 2006, when first FOSS4G project leaders joined forces to create the Open Source Geospatial Foundation (OSGeo) (www.osgeo.org) (Moreno-Sanchez, 2012). To date, this type of software has been called FOSS4G (Free and Open-Source Software for Geospatial Applications).

OSGeo is a non-profit organization with the mission to support the collaborative development of open geospatial technologies and promote their use (Franceschi *et al.*, 2019).

One of the most popular OSGeo projects in recent years is QGIS (Graser and Olaya, 2015; István, 2012; Jaya and Fajar, 2019; Sandhya, 2020; Vázquez-Rodríguez, 2018). This software was born in 2002 under the name of Quantum GIS and developed by Gary Sherman, his main aim was to show an interface to visualize geospatial data (Hugentobler, 2008; Moyroud and Portet, 2018). Although it was developed in Qt toolkit and C++, an Application Programming Interface (API) of Python was incorporated in 2007, extending its functionality and increasing the number of developers who collaborate with the improvements in the code (Graser and Olaya, 2015). It currently consists of approximately 2 million lines of code (https://www.openhub.net/p/qgis/analyses/latest/languages_summary) and is used by thousands of users around the world (https://trends.google.es/trends/explore?date=all&q=%2Fm%2F0ct9z5).

The process of incorporating developers and adding code (https://vimeo.com/431673684) has allowed QGIS to move from being just a spatial information viewer to become a powerful Geographic Information System (GIS) tool used by a wide variety of users, not only to view, but also to edit and perform complex spatial analysis (Moyroud and Portet, 2018).One of the indicators of consolidation of QGIS is the more than 16 meetings of developers held biannually since 2009, which are events organized by volunteers with the aim of bringing together the developers of the QGIS project from around the world, often within a university campus. These events are of great importance for work planning, strengthening links in the community and serving to address relevant issues on project improvements and needs (https://qgis.org/en/site/getinvolved/meetings/index.html).

Furthermore, the growing interest in this software is reflected in the structuring of 31 user groups from different countries, recognized by the QGIS project (revised in December 2020). These groups have the purpose of organizing local user meetings, participating in voting on various issues in the eyes of the international QGIS community and in some cases raise funds to contribute to the continuity of the project (https://www.qgis.org/en/site/forusers/usergroups.html).

Since its creation, FOSS4G has been a strong community and many studies have been done looking at their developments. For instance, Neteler *et al.* (2012) described the history and functionality of the more than 400 GRASS (Geographical Resources Analysis Support System) modules, free software pioneer in geosciences. In addition, Conrad *et al.* (2015) analyzed architecture, functionality, development status and implementation of SAGA (System for Automated Geoscientific Analysis), highlighting its wide spectrum of scientific applications. In terms of comparative studies, Steiniger and Bocher (2009) listed the different desktop GIS software projects and discussed the advantages and disadvantages with emphasis on research and education; István (2012) did a review on the most popular software in the field of landscape ecology; Vázquez-Rodríguez (2018) analyzed the characteristics for the estimation of statistics in raster layers; Sandhya (2020) evaluated the open source GIS software based on economic criteria, functions and abilities compared to software under commercial licenses and concludes that QGIS is the most popular user friendly leading free software. While the popularity and leadership of QGIS is perceptible, to our knowledge, there are no scientific studies addressing the role of this software in academia and research.

In that sense, scientific publications are a fundamental element in the process of dissemination of advances, knowledge generation and application and measurement of the impact on the environment of some topic or tool (Rueda-Clausen *et al.*, 2005). On the other hand, the importance of such kind of studies yields light on the directions and possibilities on the near future for the Geographic Information Systems field and, in general, for the geospatial sciences. Even more, to know current impacts of QGIS would get further developments on the programming community, since it can represent an opportunity and an exciting field to work on. In fact, studies like the present analysis could serve to bring the scientific community closer to the QGIS project, since most of the early developers and first professional users of QGIS were not academics but software developers and people working for governments. Even

today, development is driven by professional user needs more than research groups. This is a significant difference to e.g. SAGA GIS project which is driven by research groups (Conrad *et al.*, 2015).

The documentary method called bibliometric analysis has the potential to statistically study scientific production, growth, and distribution. This method is important because it is a transparent, reproducible and systematic review process with the aim of evaluating scientific activity and its impact on society (Broadus, 1987; Pritchard, 1969). Therefore, the aim of this study was to characterize the scientific production where the QGIS software was the central instrument, under the following research questions:

1) Is there a relationship over time between the number of articles that use QGIS and the increase in code contributors and income?
2) In which fields of study is most frequently the use of QGIS?
3) Which are the general characteristics of research over time, differentiated by authors, journals and countries?
4) What have been the most influential articles and authors according to number of citations?
5) What are the most important collaboration networks of countries and authors?

2. Materials and methods

A literature search was conducted using the Scopus database (https://www.scopus.com) on 15th May 2021. Scopus was chosen among scientific databases because several authors report advantages such as a larger number of journals, documents and citations reported, compared to other scientific databases (AlRyalat *et al.*, 2019; Granda-Orive *et al.*, 2013).

The word "QGIS" was used in the search process and concentrated on the title, abstract and keywords, that is, if word QGIS appeared in one of these the paper was select. The search period covered exclusively scientific contributions published from 2002 (emergence of QGIS) to 2020 (Moyroud and Portet, 2018). The query code was as follows: TITLE-ABS-KEY (QGIS) AND PUBYEAR > 2002 AND (EXCLUDE (PUBYEAR, 2021).

A dataset was built including Year, H-Index, authors, and title from each publication. A review process was carried out over the Scopus dataset to exclude publications that were not directly related to the objective of the present study. Additionally, all authors and journals names were standardized to avoid duplications and/or incorrect classification. The final dataset was the starting point for the analysis. The analysis was carried out in the free software R (R Development Core Team 2020), using the "bibliometrix" package (Aria and Cuccurullo, 2017). Total citations (TC) were calculated per publication.

Furthermore, we captured the number of QGIS code contributors (who write, develop and debug the code of program) and the total income of the QGIS project (https://www.openhub.net/p/qgis/contributors/summary; https://qgis.org/en/site/getinvolved/governance/finance/index.html). Both data were included on the dataset to understand awareness of the community and their interests, in terms of income by project. Both variables were correlated with the number of documents published over time using the Pearson's correlation algorithm.

An analysis over publications by field of study, countries, top cited manuscripts, sources, scientific collaboration networks, and coauthorships was made.

3. Results and discusión

3.1. Publication dynamics

The search on Scopus resulted in a final database with 931 scientific documents using the QGIS software as their main GIS tool (see supplementary material https://cutt.ly/6RUvGe1). It is important to note that although the search filter was set starting on 2002 (when the emergence of QGIS is reported, Moyroud and Portet, 2018), no published documents were found until 2005. Those 931 scientific manuscripts from the period 2005-2020 were included in 524 different journals, books, or conference papers. The papers were written by a total of 2,755 authors (0.29 documents per author) and until 2020 there was reported an average of 3.81 citations in Scopus (Table 1).

Table 1. Summary of the database.

Description	
Documents	931
Period	2005-2020
Average documents per year	62.06
Sources (Journals, Books, etc.)	524
Document types:	
Article	559
Conference paper	313
Book chapter	*34*
Review	*15*
Book	*4*
Conference review	*2*
Note	*4*
Keywords	2624
Average citations per document	3.81
Authors	2755
Authors per document	3.5
Documents per Author	0.29
Authors of single-authored document	79
Authors of multi-authored documents	3178

Figure 1 shows the chronological distribution of documents published in the referred period. Annual growth rate was 40.3% with an exponential behavior. The number of documents published shows a positive correlation with the number of code contributors ($r=0.66$, $p<0.005$) (Figure 2a). This is likely to make the software more attractive and robust to respond to research needs and questions and gain reputation with the scientific community (Sandhya, 2020). Conrad *et al.* (2015) mention that a rapidly growing community of users and code contributors around the world are key to the success of the software with QGIS features.

According to financial reports, total income of the project shows a significant growth from 2014 to 2020 from 28.7 k€ to 236.7 k€ respectively (Figure 1). For the period 2014 to 2020, the number of documents published had a strong and positive correlation with the total income of the QGIS project ($r=0.88$, $p<0.001$) (Figure 2b). However, the financial reports of QGIS webpage includes only the incomes of donations and payment of sponsors members. It does not include the projects which were fund by public and private institutions, neither the projects which were funding by crowdfunding.

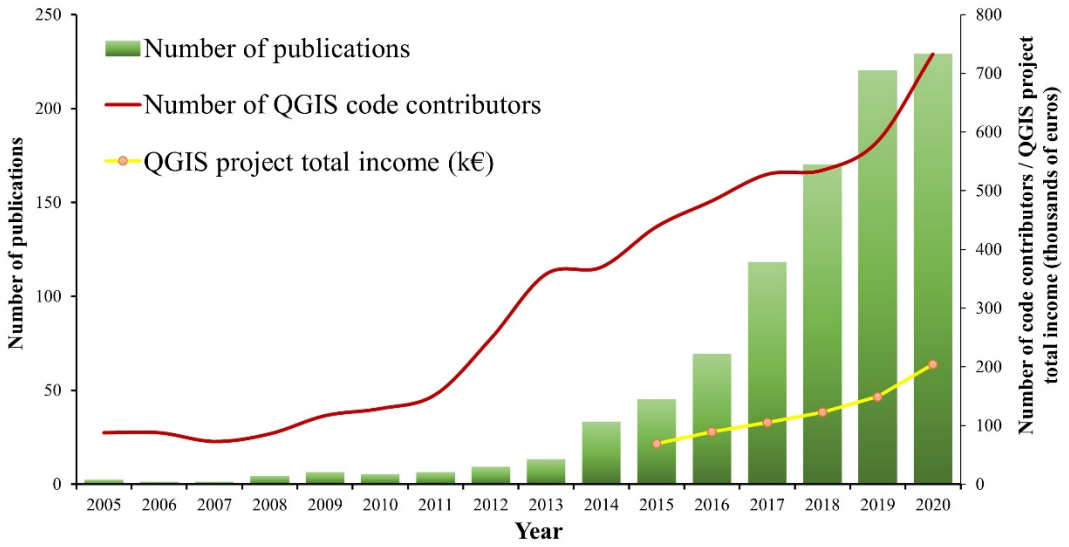

Figure 1. QGIS evolution (2005-2020) regarding number of publications (green bars), code contributors' frequency (red line) and total income by QGIS project (thousands of euros) (orange dots over a yellow line).

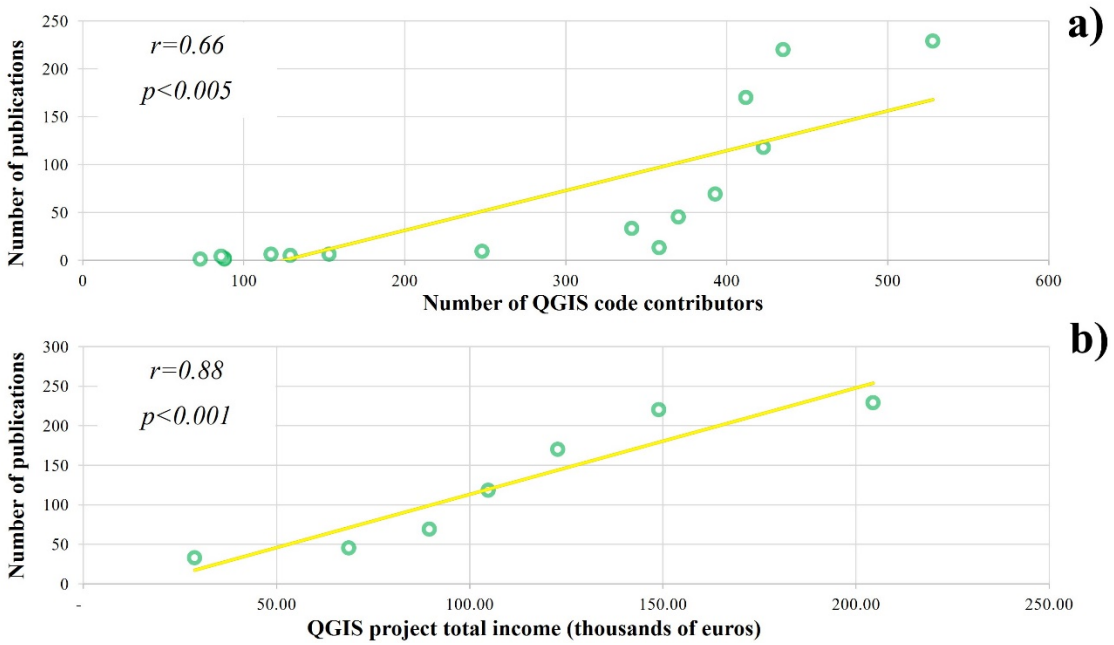

Figure 2. Pearson's correlations. a) publications vs. code contributors; b) publications vs. total income.

3.2. Publication according to the field of study

The chronological distribution of publications was analyzed according to the field of study and discipline. As illustrated in Figure 3, Earth and Planetary Sciences, Environmental Science, Computer Science, Social Sciences, Engineering and Agricultural and Biological Sciences, represent 72% of the total scientific contributions (668 documents) with 143, 132, 133, 115, 83 and 62 scientific contributions respectively. The origins of GIS are closely related to forest management or urban planning, nevertheless, at the last decades many other disciplines have incorporated the software GIS as tool (Foresman, 1998; Lünen and Travis, 2012). The interest of scientists to develop research using QGIS in these fields of study could be related to the development of the new functions and plugins.

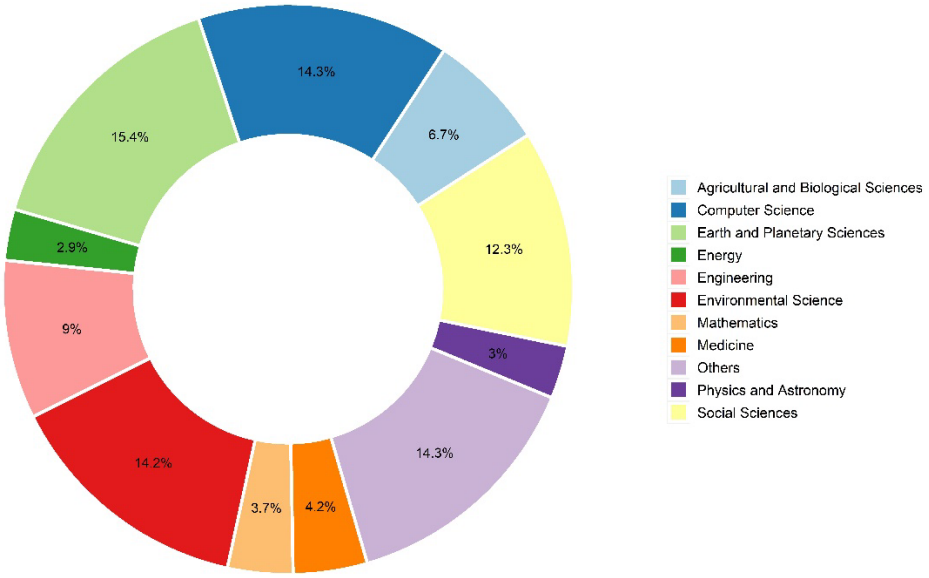

Figure 3. Chronological distribution of the 931 publications per field of study.

With respect to Earth and Planetary Sciences: Minin *et al.* (2019) used QGIS as a platform to close the gap between GIS and a virtual planetary observatory. Wolfe *et al.* (2020) developed an open source, semi-automated, QGIS-based graphical user interface (GUI) for fault-slide estimation and noted that free applications provide greater access and functionality for scientific computing and for displaying and analyzing spatial data sets. With respect to the categories Environmental Science, the application of QGIS is very varied. It has been used to assess soil erosion risk (Duarte *et al.*, 2016b), develop comprehensive GIS-based environmental management systems and specific tools for geovisual analysis (Bernasocchi *et al.*, 2012; Teodoro *et al.*, 2015), study vegetation characteristics using remote sensing (Duarte *et al.*, 2014a), analyze land use changes (Saputra *et al.*, 2020) and simulate hydrological effects (Bittner *et al.*, 2020). QGIS has been used in Social Sciences to study emotions of the population after a natural disaster (Gruebner *et al.*, 2017), geovisualization of tourists in Indonisia with Instagram data (Rofi'i *et al.*, 2019) and some other spatial data analysis with social networks (Sabah and Şimşek, 2017; Sowkhya *et al.*, 2018).

3.3. The most productive countries of corresponding authors

Overall, 75 countries published scientific contributions on the QGIS software. Italy was the country with the highest number of publications, followed by India and Brazil. Figure 4 shows the top ten of most productive countries in terms of the number of documents, and number of citations received per country. Together, these 10 countries contributed to the 30% of the total number of publications. It is important to note that five countries are in Europe, three in Asia and two in America. This indicates that, in addition to the proliferation of research using QGIS in Europe, this software has gained a reputation with the scientific community worldwide (Franceschi *et al.*, 2019). This trend could be explained by synergies of efforts such as the Open source software strategy defined and adopted by the European Commission since 2000 (Li *et al.*). This seemed to be the case in countries like Italy, which in 2010 the Constitutional Court approved the Rules on the adoption and dissemination of free software in the public administration (Corte costituzionale della Repubblica Italiana: Sentenza N. 122 2010 ("Corte costituzionale della Repubblica Italiana: Sentenza N. 122.," 2010). In South America, several efforts have been made to promote the use of free geospatial software in public administration and academia (Quinn, 2020).

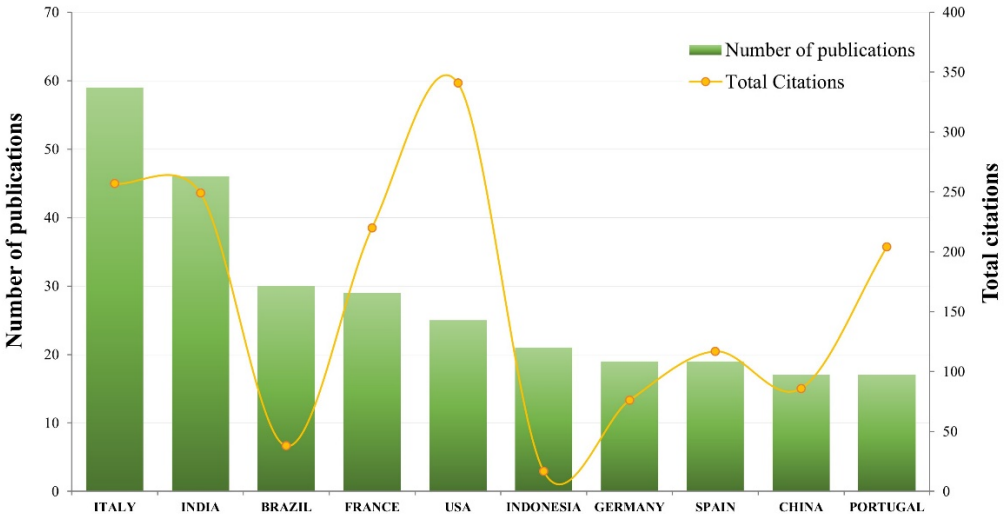

Figure 4. Number of papers and total citations received per country.

On average, these countries were cited 58 times, and while it is quite common for the countries with the highest number of publications to be those with the highest number of citations, this is not always the case. It is interesting to note the situation of Italy, India, Brazil and France. Although these four countries were the ones with the larger number of publications, the United States was the most influential country, reporting 341 total citations, almost three times more than the average per country. This may make sense due to the number of journals specialized in GIS with a high impact factor whose editorials were sitting over this country. In addition, the language of publication could be an important factor for the citation rate, often the non-English-speaking scientist decides to publish scientific articles in their first language, which makes their article less accessible to the international audience (Bitetti and Ferreras, 2017).

3.4. Top authors per number of publications

Contributions of the top 10 authors represented 9% of the total number of papers in the database. We found researchers from 5 countries: Portugal, Brazil, France, Italy and Switzerland. H-index is shown, which measures and compares productivity and impact taking into account the number of papers published and the number of citations (Jacsó, 2011). The author with the largest H-index is Zribi M. (50) who has participated in many publications about applications of QGIS (Baghdadi *et al.*, 2018a, 2018b), sometimes more than one on the same journal or book. An example of this case was the book titled "QGIS and Applications in water and risks", where Zribi M. participated as co-editor and co-author of a chapter. The aim of this book was to update knowledge of research geomatics teams, students of various levels, and engineers involved in the management of water and territory (Baghdadi *et al.*, 2018a), that exhibited the community interest to move from technical and scientific workflow to QGIS environment.

On the other hand, Teodoro A. C., Duarte L. and Rossetto R. were the authors with the largest number of papers published, with 20, 17 and 8, respectively. Teodoro A.C. and Duarte L. belonged to the University of Porto, Teodoro has published papers on risk maps and forest fire assessment (Teodoro and Amaral, 2017; Teodoro and Duarte, 2013), and participated in papers as co-author with Duarte, on developing maps for monitoring groundwater pollution vulnerability (Duarte *et al.*, 2015), as well as the development and publication of plugins for QGIS (Correia *et al.*, 2018; Duarte *et al.*, 2019; Duarte *et al.*, 2016a; Duarte *et al.*, 2018; Duarte *et al.*, 2014a; Duarte *et al.*, 2014b). It is interesting to note that a large pro-portion of papers published by Duarte are on the development of plugins, i.e. the generation

of specific functions within QGIS. This is possible thanks to the characteristics of free software that give the possibility of modifying and adapting the code to the needs of each user (Stallman, 2015).

Likewise, Rosseto R. was the main author of the development effort of the FREEWAT, plugin of QGIS, a tool for groundwater and surface water management with a module for rural water management (Rossetto *et al.*, 2018). FREEWAT was a project financed by the HORIZON 2020 programme of the European Union (Rossetto *et al.*, 2015). Since the development of FREEWAT several papers have had derivatives on its applications and improvements. For instance, De Filippis *et al.* (2020) described the supplies and workflow for using FREEWAT, also showing 13 examples from different countries. Furthermore, Criollo *et al.* (2019) introduced the ArkvaGIS module incorporated to FREEWAT that helps to store, manage and visualize the results of hydrochemical and hydrogeological analyzes.

The two authors with the largest number of contributions (Teodoro and Duarte) have produced papers from 2013 to 2019; being 2018 their most productive year. Meanwhile, Rossetto published his work from 2016 to 2020. All three authors with the largest publication numbers using QGIS have research lines on Earth and Planetary Science and Enviromental Science (Table 2).

Table 2. Most productive authors and affiliation.

Authors	ORCiD	Affiliation	Country	No. of publications	H-index
Teodoro A.C.	http://orcid.org/0000-0002-8043-6431	University of Porto	Portugal	20	16
Duarte L.	http://orcid.org/0000-0002-8043-6431	University of Porto	Portugal	17	8
Rossetto R.	http://orcid.org/0000-0003-2072-3241	Scuola Superiore Sant'Anna	Italy	8	12
Filho A.C.P.	http://orcid.org/0000-0002-9838-5337	Universidad de Federal de Mato Grosso do Sul	Brazil	7	17
Baghdadi N.	https://orcid.org/0000-0002-9461-4120	Universidad de Montpellier	France	6	49
Cannata M.	https://orcid.org/0000-0003-2527-1416	University of Applied Sciences and Arts of Southern Switzerland	Switzerland	6	11
Foti G.	https://orcid.org/0000-0001-8257-0602	University of Reggio Calabria	Italy	6	11
Mioto C.L.	https://orcid.org/0000-0002-6951-9527	Universidad de Federal de Mato Grosso do Sul	Brazil	6	8
Zribi M.	https://orcid.org/0000-0001-6141-8222	Université de Toulouse	France	6	50
Borsi I.	-	TEA SISTEMI S.p.A	Italy	5	12

3.5. Top manuscripts per number of citations

Table 3 shows the most cited papers. TC was accumulative number over time, i.e. previously published papers have cumulative advantages. Therefore, a column with citations per year is shown to put into perspective the number of citations for each paper regardless of the year of publication. Studying the number of citations of papers allows us to know the interesting topics and characteristics that confer projection among the scientific community (Patience *et al.*, 2017).

Table 3. Top Manuscripts per citations.

Manuscripts	DOI	Total Citations (TC)	TC per Year
Ilayaraja and Ambica (2015), Nat Environ Pollut Technol	-	145	20.7
Boschmann and Cubbon (2014), Prof Geogr	10.1080/00330124.2013.781490	89	11.1
Grinand *et al.* (2013),Remote Sens Environ	10.1016/j.rse.2013.07.008	83	9.2
Kaya *et al.* (2019), Hum Ecol Risk Assess	10.1080/10807039.2018.1470896	71	23.7
Dile *et al.* (2016), Environ Model Softw	10.1016/j.envsoft.2016.08.004	69	11.5
Lindberg *et al.* (2018), Environ Model Softw	10.1016/j.envsoft.2017.09.020	59	14.7
Kim *et al.* (2014), Plos One	10.1371/journal.pone.0098043	59	7.4
Chen *et al*. (2010), J Hydro-Environ Res	10.1016/j.jher.2010.04.017	49	4.1
Thiele *et al.* (2017), Soild Earth	10.5194/se-8-1241-2017	46	9.2
Jung (2016), Ecol Informatics	10.1016/j.ecoinf.2015.11.006	44	7.3

The paper with the highest number of citations was that by Ilayaraja and Ambica (2015) with 20.7 citations per year. This manuscript was published in the Nature Environment and Pollution Technology journal. This research consists in an interpolation analysis on a river using QGIS with the aim of describing water quality across the India´s river. On the other hand, in 2013 Boschman and Cubbon used QGIS to illustrate the use of maps in social research as a resource for qualitative interviews and community mapping (Boschmann and Cubbon, 2014). Boschman and Cubbon highlighted the use of QGIS in both, natural and social sciences.

In addition, Grinand *et al.* (2013) made a multitemporal analysis over the dry forest of Madagascar. The lost forest area was estimated from 2000 to 2010, through the use of remote sensing techniques and open-source software (R, GRASS y QGIS). Likewise, Kaya *et al.* (2019) published in the Journal Human and Ecological Risk Assessment: An International Journal with the title "Spatial data analysis with R programming for environment". Kaya et al included the use of QGIS, coupled with the R software in order to conduct a water quality spatially explicit assessment. These papers highlighted the capacity for integration between visualization and analysis processes of QGIS and other open-source software such as R, SAGA GIS, GRASS GIS, among others (Lush and Lush, 2014; Muenchow *et al.*, 2017; Passy and Théry, 2018).

A significant proportion (30%) of the most cited papers aimed to raise awareness of the development of plugins within the QGIS environment (Dile *et al.*, 2016; Jung, 2016; Lindberg *et al.*, 2018; Teodoro and Duarte, 2013). This can be explained if we take into account that one of the most relevant features of QGIS is that it has a Python API, which represents an advantage in terms of speed and ease in the development of new features (Graser and Olaya, 2015), allowing more interested people around the world to actively participate in the development of the software (Sarı *et al.*, 2019).

3.6. Most relevant sources

An analysis of the journals with the larger number of publications (Table 4) showed that 19.6% of publications were found in only 10 of the 524 total journals. In particular, two journals stood up: The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives (47) and the IOP Conference Series: Earth and Environmental Science (28). The journal with the larger impact factor was Environmental Modelling and Software with 4.55; the fact that this journal had the larger number of papers could be due to the preference of the authors to publish in journals that guarantee high projection among the scientific community.

Table 4. Top journals.

Sources	Total Publications	Impact Factor
International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences - ISPRS Archives	47	0.93
IOP Conference Series: Earth and Environmental Science	28	0.45
International Multidisciplinary Scientific Geoconference Surveying Geology and Mining Ecology Management SGEM	19	0.24
Proceedings of SPIE - The International Society for Optical Engineering	17	0.56
Anuario Do Instituto De Geociencias	15	0.23
Remote Sensing	14	4.51
Environmental Modelling and Software	13	4.55
ISPRS International Journal of Geo-Information	12	2.24
Lecture Notes in Computer Science	10	1.17
ISPRS Annals of The Photogrammetry Remote Sensing and Spatial Information Sciences	8	-

3.7. Analysis over scientific collaboration networks

3.7.1. Countries' collaboration

Another important topic for analysis, in addition to quantity indicators, was to analyze the existing networks of scientific collaboration. Figure 5 illustrates the links between each of the countries. The network was built taking into account the number of citations between documents, i.e. the number of citations of documents from another country that contain a document from a particular country. It is important to note that isolated nodes were removed; therefore, the network of collaborating countries consisted of 21 nodes and 45 links between 2005 and 2020.

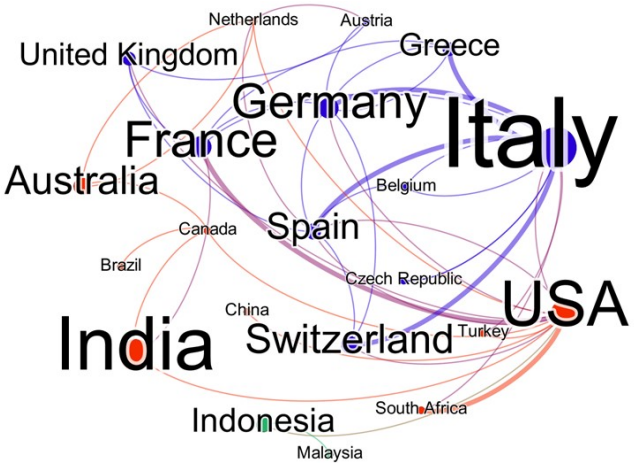

Figure 5. Countries' collaboration network.

Figure 5 indicates how strong the collaboration networks are between countries. USA, Italy, and India have larger circles than other countries, indicating that they are more productive in this area of research, which is consistent with the information in Figure 4. The arrows suggest strong links among authors from the USA with France, and USA with South Africa. Italy's strongest relationships are with Germany, Switzerland, Greece, and Spain. It is important to note that the thinness of links implies a low level of cooperation. It should be noted that Brazil, although it is the third country with the highest number of articles published, is one of the ones with the fewest collaboration links. This suggests that international collaborative networks are extremely important; however, there are countries with strong internal scientific production networks.

3.7.2. Authors' collaboration

The relationship of co-authorship in the scientific contributions contained in Scopus allows us to analyze to some extent the structure of collaboration within an academic community. In this study, with the information obtained from the authors, the productivity and collaboration network of authors who have published some work using the QGIS software as a central tool was built.

The science of our time is done in collaboration in different fields of knowledge. In the scientific work on QGIS it was observed that there is little collaboration. Figure 6 shows the relationships of scientific collaboration between authors who have published some work in the information sources consulted. Isolated nodes were removed resulting in a collaborative network with 19 authors and 31 collaborative links. The circles represent the authors, and the lines indicate the collaborations between them. The size of the circles indicates greater or lower number of studies carried out by an author. Five well-defined groups of collaboration were found, the largest was the group formed by the collaboration of seven authors, followed by the group formed by five authors, a third group is formed by three authors,

and finally two groups with two authors, suggesting developing networks of collaboration. The network formed by Duarte I, Teodoro AC and Gonçalves JA works in monitoring of natural resources topic. Rossetto R, Foglia I, Borsi I, Pouliaris C, De Filippis G, Cannata M and Kallioras A form a network specialized in water resources management. While, Korzun VA, Orgilbayar I, Tsogbadrakh N., Tserennorov D and Balakhonov SV use QGIS for epidemiological analyzes. That showed there are collaboration networks in several disciplines which use QGIS.

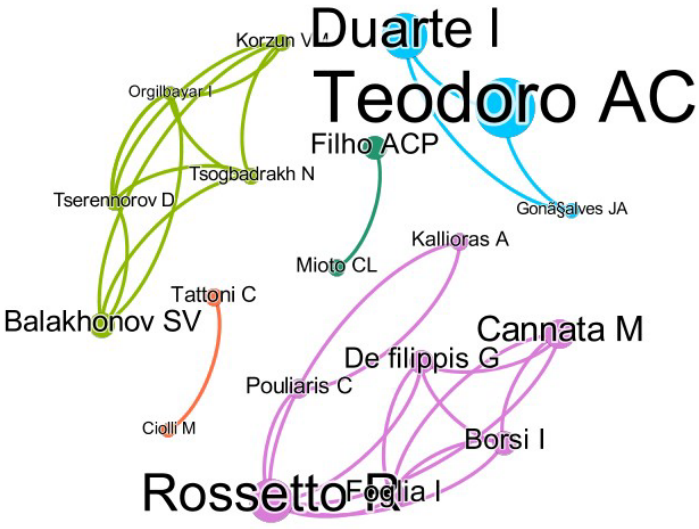

Figure 6. Authors' collaboration network.

4. Conclusions

QGIS constitutes a strong, wide, and diverse software who reflects the interest of the scientific community regarding geospatial sciences. The use of bibliometric techniques allowed us to have an overall view of the interest from the scientific community over the spatially explicit free software, and, in specific, over QGIS software.

We can conclude as well that there is a growing acceptance of QGIS by the scientific community as a tool in the development and analysis of research. Its success has been largely influenced by the extensibility of the software, and the dissemination of scientific studies on development of plugins and applications in various areas of knowledge. The present study contributes to answer the starting questions at the following highlights:

1) There is a relationship between the number of articles and the number of programmers who contributed to the code ($r = 0.66$), also with respect to the income of the QGIS project ($r = 0.88$). This indicates that the acceptance of QGIS into scientific community grows with respect to the people involved in the project. It could be interesting analyzing the income of specialized plugins and crowdfunding projects instead just the information of financial reports.

2) QGIS is used in several fields of study. The fields of study with more publications are Earth and Planetary Sciences (15.4%), Environmental Science (14.2%), Computer Science (14.3%), and social sciences (12.3%).

3) Scientific production has been on a growing trend since 2005, with an annual increase rate of 40.3%. The sources with the most publications on the subject were International Archives of Spatial Information Sciences and Remote Photogrammetry Sensing - ISPRS Archives and IOP Lecture Series: Earth and Environmental Sciences. Meanwhile, the most productive authors were Teodoro AC and

Duarte L, both authors attached to the University of Porto. Researchers from 75 countries have published articles related to QGIS, Italy and India being the most prolific countries.

4) The articles most cited in the period studied (2005-2020) were Ilayaraja and Ambica (2015) y Boschmann and Cubbon (2014), from Earth and Planetary Sciences and social sciences respectively. In addition, the most frequent fields of study were: Earth and Planetary Sciences (15.4%), Enviromental Sciencie (14.2%), Computer Science (14.3%), and social sciences (12.3%).

5) The most important country collaboration network is conformed for Italy, Germany, Switzerland, Greece and Spain. Author network analysis showed three solid networks in different fields of study.

The bibliometric analysis carried out with the contributions recorded in Scopus databases proved to be ideal for finding out characteristics and evolution of scientific production, where QGIS was used as the main tool. It is remarkable that every day more countries are added to the list of free software users. However, it is necessary to develop multiple studies highlighting advantages in order to promote and strengthen this culture; and thus, provide intellectual and scientific tools based on free software. In future research, it could compare trends and collaboration networks in the use of QGIS with commercial GIS software. It will also be interesting to analyze the potential of other scientific repositories.

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