WHAT IS WEB MAPPING ANYWAY?

Bert Veenendaal[1], Maria Antonia Brovelli[2], Songnian Li[3] and Ivana Ivánová[4]*

[1]Department of Spatial Sciences, Curtin University, GPO Box U1987, Perth, Australia – b.veenendaal@curtin.edu.au
[2]Department of Civil and Environmental Engineering (DICA), Politecnico di Milano, P.zza Leonardo da Vinci 32, Milan, Italy – maria.brovelli@polimi.it
[3]Department of Civil Engineering, Ryerson University, 350 Victoria St., Toronto, Canada - snli@ryerson.ca
[4]Department of Spatial Sciences, Curtin University, GPO Box U1987, Perth, Australia – ivana.ivanova@curtin.edu.au

Commission IV, WG IV/4
Commission II

KEY WORDS: Web mapping, Web GIS, Geoweb, Online mapping, Collaborative mapping, Geospatial Web Services

ABSTRACT:

Although maps have been around for a very long time, web maps are yet very young in their origin. Despite their relatively short history, web maps have been developing very rapidly over the past few decades. The use, users and usability of web maps have rapidly expanded along with developments in web technologies and new ways of mapping. In the process of these developments, the terms and terminology surrounding web mapping have also changed and evolved, often relating to the new technologies or new uses. Examples include web mapping, web GIS, cloud mapping, internet mapping, internet GIS, geoweb, map mashup, online mapping etc., not to mention those with prefixes such as "web-based" and "internet-based". So, how do we keep track of these terms, relate them to each other and have common understandings of their meanings so that references to them are not ambiguous, misunderstood or even different? This paper explores the terms surrounding web mapping and web GIS, and the development of their meaning over time. The paper then suggests the current context in which these terms are used and provides meanings that may assist in better understanding and communicating using these terms in the future.

1. INTRODUCTION

Maps and mapping have developed rapidly over the past decades as new digital and online technologies have evolved. This has created a plethora of terminology used to describe the new mapping environments. The purpose of this paper is to identify the variety of terms used to describe the new wave of web mapping and to recommend how the terms can be used in a context that promotes better understanding and communication.

2. WEB MAPPING AND GIS DEFINED

There are number of similar definitions for web mapping and web GIS used in the geodomain. Both, Web mapping and Web GIS, are usually understood as being the same thing, and most generally web mapping and/or Web GIS is "the process of designing, implementing, generating and delivering maps, geospatial data and Geographic Information Systems (GIS) functionality or services on the Web." (p. vii, Li et al., 2011a) However, in our view, there is a difference between mapping and GIS, therefore in this section, we present other, widely adopted definitions for either Web mapping or Web GIS.

2.1 Web Mapping

The Open Geospatial Consortium (OGC), a *de-facto* standardization body responsible for defining widely adopted interfaces between geospatial data and information and the Web, defines the term web mapping as "a dynamic query, access, processing, combination and portrayal of different types of spatial information over the Web" (OGC, 2017).

Mitchell (2005) defines the term *web mapping* as the concept referring to variety of applications and processes, but it most often implies a web page that has some sort of static or interactive map component.

Haklay et al. (2008) discusses emerging terminology used as synonyms to web mapping in the realm of Web 2.0, among which the concept of *neogeography* emerged which refers to the use of modern web tools for creating and sharing maps. Web 2.0 is characterized by user-generated content. When the content is geographically-referenced and there are more users generating it (i.e., mapping on the Web), the result is called *volunteered geographic information* (Goodchild, 2007).

Among more general terms, *crowdsourcing, citizen science and user-generated geographic content* are referred when talking about web mapping in Web 2.0. All the above terms are often used as synonyms and often related to a citizen involvement in carrying out various activities relating to geographic information science (See et al., 2016).

2.2 Web GIS

According to Kemp (2008), a Web GIS (also referred to as *Internet GIS*, *distributed GIS*, and *Internet mapping*) is "the implementation of GIS functionality through a World Wide Web browser or other client program, thus allowing a broader usage and analysis of a particular geographic database (p. 511, Kemp, 2008).

Marrying GIS with computer networks has formed various types of distributed GIS, such as *Network GIS* (Yang et al., 2008), *Internet GIS* (Peng and Tsou, 2003), *Intranet GIS*, *Wireless GIS*, *Distributed GIServices* (Yang and Tao, 2006), *Web GIS* (Plewe, 1997), and *Location Based Services* (Bin and Zipf, 2004). To distinguish these concepts and to give clearer definitions of

* Corresponding author

these concepts, Yang et al. (2006) argued that all of them are Network GIS geographically dispersed in the allocation of geospatial information resources and geospatial computing.

2.3 Geospatial cyberinfrastructure and geosemantic web

With the adoption of the term cloud computing in early 2000s for "enabling ubiquitous, on-demand access to a shared pool of configurable computing resources (e.g., computer networks, servers, storage, applications and services)" (p.2, Mell and Grance, 2011), the terms such as *Cloud GIS*, *Cloud mapping*, *Geocloud*, *Spatial Cloud Computing* and *Geospatial cyberinfrastructure* have emerged and are frequently used as synonyms to any term used in the context of distributed, Inter-/Intranet, wireless, web or network GIS.

In the cloud computing era, the process analogous with web mapping is called *spatial cloud computing* and it is a paradigm driven by geospatial sciences, and optimized by spatiotemporal principles for enabling geospatial science discoveries and cloud computing within distributed computing environment (Yang et al., 2010). *Geospatial cyberinfrastructure* refers to an infrastructure that supports the collection, management, and utilization of geospatial data, information, and knowledge for multiple science domains. (Yang et al., 2011). Such an infrastructure utilizes various resources in a framework scalable along three dimensions: functions, communities and enabling technology (Yang et al., 2010).

Web 3.0, or semantic web (Berners-Lee et al., 2001), is one of the most recent developments, which influences the meaning and the use of the web mapping concept. In this context, except referring to the processes related to creation and dissemination of geospatial information, *geosemantic web mapping* includes capture and dissemination of the meaning of geographic phenomena, processes and resulting knowledge represented on the Web[1]. With access to the meaning of geographic phenomena (represented by data, maps or images), future systems will be realizing automated web mapping in real-time, for instance only by simple search for spatial knowledge (Ivánová et al., 2013; Reed et al., 2016; Scharl and Tochtermann, 2007).

3. DEVELOPMENTS IN WEB MAPPING AND GIS TERMINOLOGY

Web mapping is used to refer to the mapping environment that has migrated to and developed on the web. This has happened together with other related developments including *GIS* moving more into an online environment, and the increasing use of *geospatial web services*. The result is that the usage of these terms has morphed closer to each other, overlapped and sometimes even used synonymously. The following sections identify some of the developments in the use of terms surrounding web mapping, GIS and geoweb.

3.1 Mapping, GIS and the web

Mapping and *GIS* have developed rapidly over the past decades due to many advances in technologies and their use. Both terms have also expanded simultaneously with their developments on the web. *Web mapping* and *web GIS* are now commonly used and particularly emphasize the web environment in which they operate. When referring to the whole range of such developments on the web, both terms are sometimes used together to ensure that all aspects of mapping and GIS on the web are covered or the terms have also been used synonymously (Fu and Sun, 2011; Li et al., 2011b). Of course the terms mapping and GIS are not synonymous, but distinct in that mapping is the process of building a geographic representation referred to as a map, whereas GIS is a system for representing, manipulating, analyzing and visualizing geospatial data, including building a map. Hence, in a web environment, the same distinctions apply albeit in a different environment. In fact, many of the geospatial terms in a web environment arise from either the information technology (IT) terms themselves, geospatial terms or even social terms (Table 1).

IT terms	Geospatial terms	Social terms	Geospatial + Web terms
	Mapping		Web mapping
	GIS		Web GIS
Web			Geoweb
Web services			Geospatial web services
Cloud			Geocloud, Cloud GIS, Cloud mapping
Mobile			Mobile GIS, Mobile mapping
Internet			Internet GIS, Internet mapping
		Collaborative	Collaborative mapping
		Participatory	Participatory mapping
		Interactive	Interactive mapping

Table 1. Web-related geospatial terms from IT, geospatial and social contexts

The web environment has impacted mapping and GIS in that they themselves have been developed further due to the advance of web technologies. For example, because of the web, mapping has become more interactive and GIS more collaborative as users can interact with maps and apply geospatial functionality to the underlying geospatial data (Li et al., 2011b; Peterson, 2014; Veenendaal et al., 2017). This also influences how terminology has been developed.

The web environment has also impacted mapping and GIS by moving beyond their boundaries. The fact that online technologies have revolutionized mapping and GIS by manipulating the underlying data and functionalities, has resulted in *web services* being developed to encapsulate data and functionality into online components with an application programming interface (API). Geospatial information and functions can now be accessed by web services, termed *geoweb services* to distinguish them from non-geospatial. Terms like web map services, geospatial web services, online mapping services and mapping web services (or web mapping services) have been used as synonyms (Fu and Sun, 2011). Although not strictly web mapping in that they do not necessarily produce maps, geoweb services manipulate geospatial information, may produce maps, and are increasingly the technology used to retrieve, analyse and model the information that ends up on maps or is used via computer programming interfaces in further geospatial applications. This way, the "users" of these geoweb services are not only human end-users, but also other application software programs that can consume and use geospatial information.

Trying to capture the concepts of this confluence of geospatial and web developments – web mapping, web GIS and geoweb services – has been a challenge and different terms have been used for this. The first phrase encapsulating this confluence appears to be "spatialization of the Internet" (Herring, 1994). It was not until almost a decade later that terms such as *geospatial*

[1] https://www.w3.org/2015/spatial/wiki/Main_Page

web or *geoweb* for short began to be used (Lake et al., 2004; Hacklay, 2004; Scharl and Tochtermann, 2007; Li et al., 2011b). *Geoweb* is defined as an

> "interconnected, online digital network of discoverable geospatial documents, databases and services" (p.3, Turner and Forrest, 2008)

or more detailed as

> "an integrated, discoverable collection of geographically related Web services and data that spans multiple jurisdictions and geographic regions. In a broad sense, the Geospatial Web refers to the global collection of general services and data that support the use of geographic data in a range of domain applications." (p. 15, Lake and Farley, 2009).

These definitions, explicitly or implicitly, cover all aspects of geospatial data and functionality in the context of their use in applications. This then covers all aspects of mapping, GIS and services on the web, including continuing developments in semantics, knowledge-building, sensor networks, geovisualization, geoanalytics, etc.

3.2 Context of terminology

As developments in technology occur, the terminology used often expands to identify the new context of these technologies. For example, when GIS software moved from the desktop to the Internet environment, they were sometimes referred to as *Internet GIS* (Peng and Tsou, 2003). Also, when mapping shifted from static mapping to adopt dynamic and interactive web technologies like AJAX and Web 2.0, it was referred to as *interactive mapping* or *web mapping*. The term *interactive mapping* has subsequently expanded to include the functionality with web GIS, which itself is continuing to evolve and expand (Steinberg and Steinberg, 2015).

Synonyms for a term are often used because of the various perspectives that users take, for example *web mapping*, *interactive mapping* and *cloud mapping*. In essence, these terms are synonymous since the mapping using the web means that the maps became interactive from a user perspective and could be implemented using cloud computing from an infrastructure perspective. However, in their usage the different terms may have some distinct implications. For example, web mapping implemented via some online web services may not necessarily utilize cloud computing technologies.

The perspectives in which a term can be used include: the media used for implementation or communication, content-related and usage-based.

3.2.1 Media focussed terms: When maps started to be placed online, the term *online mapping* became used to distinguish it from the traditional infrastructure used to generate maps, namely, the desktop computer. So the intent was to focus on the fact that maps were now online on the web. Related terms identifying the online medium for mapping are *Internet mapping* and *web mapping* (see Figure 1). Although used synonymously, the terms *Internet* and *web*, short for *World Wide Web*, are distinguished in that the Internet refers to the network infrastructure while the web refers to a large multimedia application that operates on the Internet (Peng and Tsou, 2003).

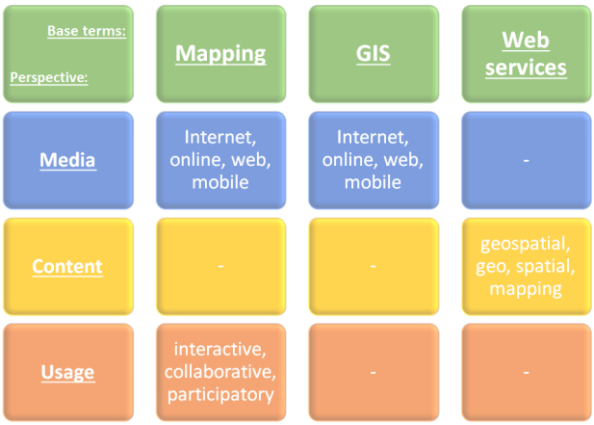

Figure 1. Terms used for mapping, GIS and web services from the perspective of media, content and usage

With the advent of mobile devices and the use of maps on them, the term *mobile mapping* was also used; however, this should not be confused with the capture of 2D and 3D data using mobile devices such as laser scanners, which is also termed *mobile mapping*. This latter case is a prime example where terms can easily double up and cause confusion or ambiguity.

When the cloud, and in particular cloud computing, was used to host maps (Peterson, 2014), the focus on this infrastructure became apparent in the term *cloud mapping*. For example, when considering *web mapping* from the perspective of using cloud services and infrastructure to host it, this term can be referred to as cloud mapping, for example, the title of a book "Mapping in the Cloud" (Peterson, 2014). Also, a number of geospatial organisations refer to the terms, as is evident from a quick search on the web.

The focus of the changing media and underlying infrastructure was also apparent in the terms surrounding *GIS* (Figure 1). Terms used to highlight the move of GIS and GIS functionality to the web include *Internet GIS*, *online GIS* and *web GIS*, similar to those for *mapping*. The use of mobile devices for mapping similarly resulted in the term *mobile GIS* (Drumond et al., 2007; Xia et al., 2016).

3.2.2 Content focussed terms: In some cases the new or changing content has been integrated into the use of a term. This is the case particularly with a term like *web services* applied to geospatial data and applications. *Geospatial web services*, or *geoweb services* for short, *spatial web services* and *web map services* are all terms that illustrate this (Figure 1). Interestingly, but as can be expected, the terms *mapping* and *GIS* are not influenced by the content, since they are supposed to be more generic and apply to a whole range of different applications and contents.

3.2.3 Usage focussed terms: As the underlying technologies develop, the characteristics of systems and usage may develop and change. These characteristics may also find their way into the terminology used to distinguish the new systems from the traditional or older implementations. For example, with the development of AJAX and Web 2.0 technologies, online mapping interfaces became much more interactive and allowed users to share and contribute content. Terms such as *interactive mapping* and *collaborative mapping* are used to express these characteristics (Figure 1) (Bernardin et al., 2006; Rouse et al., 2009; Aye et al., 2016). Even terms like *participatory mapping*

and *community mapping* are implying online mapping because of the developments and benefits of using the web in participatory mapping processes (Plantin, 2014).

4. FRAMEWORK FOR GEOWEB TERMINOLOGY

With a reference to the discussion in Section 3, we suggest the following use for the terminology (see Figure 2):

- *Geospatial web* – for a subset of the Web that contains geospatial data and processes.
- *Geospatial web mapping* – for a process of building geographic representation referred to as a map.
- *Geospatial web GIS* – for a system used for representing, manipulating, analyzing and visualizing geospatial data, including building a map.
- *Geospatial web services* – for a self-contained, self-describing, modular applications that can be published, located, and invoked across the Web (OGC, 2017).

There are several synonyms used with the geospatial web mapping and geospatial web GIS core concepts (see Figure 2).

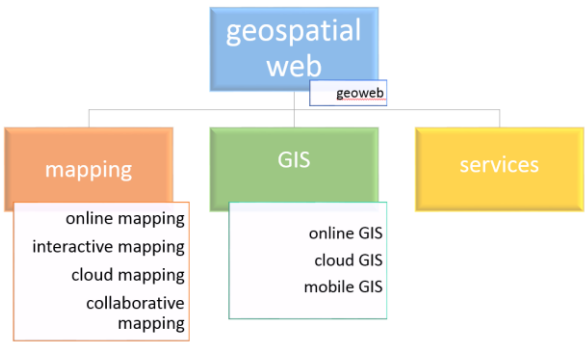

Figure 2. Framework of geoweb and related terms

The concept and practice of web mapping has dramatically changed in time, following the evolution of the interaction among the mapping data/information, the Internet, the web, the available tools and its users' attitude. If we want to summarize in few words we can say that the web mapping is a website with mapping capability. The capability has grown in time and the interest of the people in consuming (and more recently in contributing to) those websites has grown accordingly.

There are different terms which are used as synonyms of *geospatial web mapping*; they may have slightly different meanings or, at least, refer to different stage (and characteristics) of web mapping. For instance, *online mapping* is a wide meaning term, which means, following the definition of "online" (Oxford Dictionaries, 2017), that the mapping is available on or performed using the Internet or other computer networks.

Interactive mapping is properly used to denote a type of web mapping based on AJAX or similar technologies combined with image tiling, which allow online maps to be delivered to a user in a continuous and responsive manner. A second relevant aspect of interactive mapping is the possibility of mashups, i.e., the dynamic and personalized combination of data from multiple sources combined into one map (Wood et al., 2007, Li and Gong, 2008).

With the term *cloud mapping*, the emphasis is put on the cloud technology, which provides resource pooling, virtualized applications and a shared platform from which mapping applications and databases can be built, integrated and shared on the web. Examples include Amazon's cloud storage and web services, Microsoft Azure cloud, ESRI's ArcGIS Online, GeoNode, GIS Cloud, and CartoDB. The cloud provides a platform to manage and manipulate Big Geospatial Data which is a characteristic of the growing volumes of geospatial data being collected through sensors and mobile devices (Lee and Kang, 2015).

If cloud mapping is more about the server side, the *collaborative mapping*, derived from the Web 2.0 developments, refers to the way in which more users participate, not only in the use of web maps, but also in data creation activities. OpenStreetMap (2017) and Wikimapia (2017) are the most relevant examples of collaborative mapping.

Coming to the "GIS branch" of the tree in Figure 2, the main remark concerns the fact that we are considering (and proposing to use) only the term *web GIS*. The term *Internet GIS* is used mainly due to historical reasons. In fact, the first scientific and technical contributions (papers, books, etc.) related to the *online GIS* used the term Internet associated to the GIS. As already mentioned, Internet GIS (Peng and Tsou, 2003) is an Internet geospatial application which uses more services than the Web. It is broader with respect to the applied technology, but not as pervasive as Web GIS (Google, 2017). Internet GIS are those systems that use the Internet as the supporting network infrastructure and that follow all Internet protocols, but they do not necessarily use the World Wide Web to provide a front-end interface. In this sense, the use of the web to run its user interfaces may be considered as one distinct feature between Internet GIS and Web GIS. *Online GIS*, exactly like online web mapping, is a broad term and can be considered as synonym of Internet GIS.

Cloud GIS refers to the platform which is used for sharing data and functionality. Being implied with the term (and concept) GIS, it means that it is more than cloud mapping. It is a fully-fledged GIS that takes advantage of the cloud and web technologies for the communication among its components: retrieving, processing and sending any kind of geospatial data and information. This is in line with the trend of moving office tools onto the cloud computing platforms, such as Google Docs and Microsoft Office on Onedrive.

Finally, a *mobile GIS* is an integrated software/hardware framework for accessing geospatial data and location-based services through mobile devices via wired or wireless networks (Tsou, 2004). Therefore, in this case the term highlights the device allowing the interaction with geospatial data and processing because on one side these tools are more limited (for instance for the visualisation of maps, due to the small dimensions of the screen), and on the other side they allow for content generated in the field, increasing accuracy and saving time.

5. CONCLUSIONS

There exists a diversity of terms in the geospatial and web disciplines over time and often referring to the same thing. This paper identifies some of this diversity and provides a framework of terminology with the goal to provide a common way forward in the use of geoweb terms.

As there are developments in the integration and expansion of geospatial and web technologies, the terminology expands with reference to the new technologies or context. This referencing is intended to highlight the changes or developments in the new context. An example was the transition of GIS into an online environment and being referred to with terms such as online GIS, Internet GIS and web GIS.

The geospatial web and associated components including geospatial web mapping, GIS and services, will continue to develop and evolve with new terms appearing in relation to media, content and usage. These are positive developments to be encouraged; we hope that this paper will help to guide the terminology of the future geospatial web.

1. REFERENCES

Aye, Z. C., Jaboyedoff, M., Derron, M. H., van Westen, C. J., Hussin, H. Y., Ciurean, R. L., Frigerio, S., and Pasuto, A. 2016. An interactive web-GIS tool for risk analysis: a case study in the Fella River basin, Italy, *Natural Hazards Earth System Science*., 16, 85-101, https://doi.org/10.5194/nhess-16-85-2016, 2016.

Bernardin, T., E. Cowgill, R. Gold, B. Hamann, O. Kreylos and A. Schmitt 2006. Interactive mapping on 3-D terrain models, Geochem. Geophys. Geosyst., 7, Q10013, doi:10.1029/2006GC001335

Berners-Lee, T., Hendler, J. and Lassila, O. 2001. The Semantic Web. *Scientific American Magazine*.

Bin, J. and Zipf Alexander. 2004. An Introduction to the Special Issue on LBS and GIS, Geographic Information Sciences, 10:2, 89-90, DOI:10.1080/10824000409480659

Drumond, J., Billen, R., João, E. and Forrest, D. 2007. Dynamic and Mobile GIS, CRC Press, Taylor and Francis Group: Boca Raton, 300p., ISBN: 0‐ 8493‐ 9092‐ 3

Fu, P. and J. Sun. 2011. *Web GIS: Principles and applications*. Esri Press, Redlands, California.

Goodchild, M.F. 2007. Citizens as sensors: The world of volunteered geography. *GeoJournal*, 69 (4), 211-221, DOI: 10.1007/s10708-007-9111-y.

Google Trends. 2017. https://trends.google.com/ (14 July 207).

Haklay, M., Singleton, A. and Parker, C. 2008. Web Mapping 2.0: The Neogeography of the GeoWeb. *Geography Compass*, 2/6, pp 2011-2039.

Herring, C. 2004. An Architecture of Cyberspace: Spatialization of the Internet. U.S. Army Construction Engineering Research Laboratory.

Ivánová, I., Morales, J.M., de By, R.A., Beshe, T., S., and Gebresilassie, M.A. 2013. Searching for spatial data resources by fitness for use. Journal of Spatial Science, Vol.58, Nr. 1, Taylor and Francis, London

Kemp, K. 2008. *Encyclopedia of Geographic Information Science*. SAGE Publications, Inc; 1 edition.

Lake, R., Burggraf. D., Trninic, M. and Rae, L. 2004. *Geography Mark-Up Language: Foundation for the Geo-Web*. Wiley.

Lake R. and Farley J. 2009. Infrastructure for the Geospatial Web. In: Scharl A., Tochtermann K. (eds) *The Geospatial Web. Advanced Information and Knowledge Processing*. Springer, London, pp. 15-26

Lee, J.G. and Kang, M. 2015. Geospatial Big Data: Challenges and Opportunities. Big Data Research, 2 (2), pp. 74-81.

Li, S, S Dragićević, S and B Veenendaal. 2011a. *Advances in Web-based GIS, Mapping Services and Applications*. Taylor and Francis Group, London, ISBN 978-0-415-80483-7.

Li, S, J Gong. 2008. Mashup: A new way of providing web mapping/GIS services. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVII, Part B4, Beijing 2008.

Li, S, B Veenendaal and S Dragićević. 2011b. Advances, challenges and future directions in web-based GIS mapping services. In Li et al. (2011a) A*dvances in Web-based GIS, Mapping Services and Applications*. Taylor and Francis Group, London.

Mell, P and Grance, T. 2011. The NIST definition of Cloud Computing, NIST, Geithersburg, 3p. http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf (17 July 2017)

Mitchell, T. 2005. Web Mapping Illustrated, O'Reilly Media, Inc.: Sebastopol, ISBN 978-0-596-00865-9, 349p.

Open Geospatial Consortium (OGC). 2017. Glossary of Terms. OGC, Wayland, USA, http://www.opengeospatial.org/ogc/glossary (17 July 2017)

OpenStreetMap, 2017. Available online: https://www.openstreetmap.org/ (17 July 2017)

Oxford Dictionaries, 2017, Available online: https://en.oxforddictionaries.com/definition/online (17 July 2017).

Peng, Z. and Tsou, M. 2003. *Internet GIS: Distributed Geographic Information Services for the Internet and Wireless Networks.* New Jersey: John Wiley and Sons, Inc.

Peterson, Michael P. 2014. *Mapping in the Cloud*. The Guilford Press, New York, ISBN 978-1-4625-1041-2.

Plantin, Jean-Christophe. 2014. *Participatory Mapping: New Data, New Cartography*. ISTE Ltd. and John Wiley and Sons Inc., Great Britain.

Plewe, B. 1997. GIS Online: Information Retrieval, Mapping, and the Internet. OnWord, Santa Fe.

Reed, T. W., Gulland, E-K., West, G., McMeekin, D. and Moncrieff, S. 2016. Geographic Metadata Searching with Semantic and Spatial Filtering Methods, In *Proceedings of the GEOProcessing 2016 : The Eighth International Conference on Advanced Geographic Information Systems, Applications, and Services*, 2016, pp.85-92, IARA: Venice, ISBN 978-1-61208-469-5

Rouse L.J., Bergeron S.J., Harris T.M. 2009. Participating in the Geospatial Web: Collaborative Mapping, Social Networks and Participatory GIS. In: Scharl A., Tochtermann K. (eds) The Geospatial Web. Advanced Information and Knowledge Processing. Springer: London, pp. 153-159

Scharl, Arno and Klaus Tochtermann (Eds.) 2007. *The Geospatial Web: How Geobrowsers, Social Software and the Web 2.0 are Shaping the Network Society*. Advanced Information and Knowledge Processing Series, London: Springer.

See, L., Mooney, P., Foody, G., Bastin, L., Comber, A., Estima, J., Fritz, S., Kerle, N., Jiang, B., Laakso, M., Liu, H.-Y., Milčinski, G., Nikšič, M., Painho, M., Pődör, A., Olteanu-Raimond, A.-M. and Rutzinger, M. 2016. Crowdsourcing, Citizen Science or Volunteered Geographic Information? The Current State of Crowdsourced Geographic Information. *ISPRS Int. J. Geo-Inf.* 2016, *5*, 55, http://dx.doi.org/10.1016/j.compenvurbsys.2010.04.001.

Steinberg, S. L. and Steinberg. S.J.. 2015. *GIS Research Methods: Incorporating Spatial Perspectives*. Esri Press, Redlands, California.

Tsou, M.-H. 2004. Integrated Mobile GIS and Wireless Internet Map Servers for Environmental Monitoring and Management. *Cartography and Geographic Information Science*. 31(3), pp. 153-165, doi: 10.1559/1523040042246052.

Turner, A. and B. Forrest. 2008. Where 2.0: The State of the geospatial web. An O'Reilly Radar Report, Sebastopol, CA.

Veenendaal, B., Brovelli, M. and Li, S. 2017. Review of Web Mapping: Eras, Trends and Directions. Submitted manuscript in review.

Wikimapia, 2017. wikimapia.org (17 July 2017)

Wood, J, Dykes, J., Slingsby, A. and Clarke K. 2007. Interactive visual exploration of a large spatio-temporal data set: reflections on a geovisualization mashup. IEEE *Transactions on Visualization and Computer Graphics*, 13(6), pp.1176-1183, doi: 10.1109/TVCG.2007.70570.

Xia, J., Dong, P. and Tang, J. 2016. Efficient rendering of natural hazards data in mobile GIS, *Geomatics, Natural Hazards and Risk*, Volume 7, Issue 5, pp.1726-1730, DOI: 10.1080/19475705.2015.1084954

Yang C.P. and Tao C.V. 2006. Distributed Geospatial Information Service. In: Rana S., Sharma J. (eds) *Frontiers of Geographic Information Technology*. Springer, Berlin, Heidelberg, ISBN 978-3-540-25685-4, 329p.

Yang, C., D. Wong, M. Kafatos and R. Yang. 2006. Implementing computing techniques to accelerate network GIS. In *Proceedings of SPIE the International Society for Optical Engineering*. Vol. 6418, 64181C, Geoinformatics 2006: GNSS and Integrated Geospatial Applications, eds. D. Li and L. Xia. Bellingham, WA.

Yang, Ch., Goodchild, M., Huang, Q., Nebert, D., Raskin, R., Xu, Y., Bambacus, M. and Fay, D. 2011 Spatial cloud computing: how can the geospatial sciences use and help shape cloud computing?, *International Journal of Digital Earth*, Volume 4, Issue 4, pp.305-329, DOI: 10.1080/17538947.2011.587547

Yang, Ch., Li, W., Xie, J. and Zhou, B. 2008. Distributed geospatial information processing: sharing distributed geospatial resources to support Digital Earth, *International Journal of Digital Earth*, Volume 1, Issue 3, pp. 259-278, DOI: 10.1080/17538940802037954

Yang, Ch, Raskin, R., Goodchild, M.F. and Gahegan. 2010. Geospatial Cyberinfrastructure: Past, present and future, *Computers, Environment and Urban Systems*, Volume 34, Issue 4, 2010, pp. 264-277, ISSN 0198-9715, DOI: 10.1016/j.compenvurbsys.2010.04.001