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Top-cited articles in environmental sciences: Merits and demerits of citation analysis

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ABSTRACT

The purpose of this study was to identify the top-cited articles published in environmental science journals listed in Journal Citation Reports (JCR). The Web of Science database was used to retrieve the top-cited articles having 500 or more total citations from their publication to 2010. The articles were analyzed with regard to institution and country of origin with five indicators including total number of top-cited articles, as well as independent, collaborative, first author, and corresponding author articles. Article life was also investigated for history of impact of articles. Results showed that 88 articles were cited more than 500 times. These articles appeared in 26 different journals, with 28% of all top-cited articles in *Environmental Science & Technology*, followed by *Water Resources Research*. The top-cited articles published since 1971 to 2002 were from 17 countries. The USA published the most of the articles and was ranked on top among the five indicators. The U.S. Geological Survey was the most productive institution while, the Brunel University, UK published the most inter-institutionally collaborative and corresponding author articles under environmental science category.

1. Introduction

Environmental science is a multidisciplinary field of research. It specifically focuses on water, air, soil, and climate research (Wang and Ho, 2011). Since the evolution of planet Earth, exponential increase in human population has created a corresponding increase in their demand to utilize various natural resources causing adverse effects on ecosystem. Concerning these aspects environmental scientists around the world are trying to minimize this ecological imbalance. Recent decades have brought an alarming concern on the issue as evident from citation analysis and increasing impact of environmental science journals. Bibliometric data analysis since 2004 revealed wastewater research as a hottest most topic under this category (Wang and Ho, 2011). The number of citations previously published work achieved is an indication of its subsequent recognition and impact in an area of research (Smith and Rivett, 2009).

The impact of scientific research on scientific community could be testified by "citation analysis" (Moed, 2005). Citation analysis is an analytical methodology under bibliometrics used to evaluate research performance. This analysis utilizes citation data used to quantify the impact of research as illustrated by the number of references that an article receives over time. The citation frequency is assumed to reflect the impact of journal articles, although not necessarily their quality (Brandt et al., 2010). This highlights the failure of database to distinguish between positive and negative credits of citations. Bibliometric investigations have been carried out in specific science citation index (SCI) subject categories, especially medical related fields, including general and internal medicine (Foo, 2009), dentistry, oral surgery and medicine (Gil-Montoya et al., 2006), tropical medicine (Falagas et al., 2006), virology (Falagas et al., 2005), psychology (Lluch, 2005), oncology (Ugolini et al., 2002), and ophthalmology (Ugolini et al., 2001). Studies related to the environmental fields for example ocean engineering (Dastidar and Ramachandran, 2005), water resources (Wang et al., 2011), and environmental sciences (Wang and Ho, 2011) were also presented. The best article can be classified as an article that may be read by most of the people and also cited in peer reviewed journals (Robinson and Callen, 2010). Analysis of the top-cited articles in a field provides a historical perspective in the scientific advancement of research, evolution (Ohba et al., 2007), and areas of intensive research activities (Tsai et al., 2006). It was found that the top articles were published in high-impact journals in obstetrics and gynecology (Brandt et al., 2010). The authors from North America have had more top articles in rehabilitation, obstetrics and gynecology fields (Shadgan et al., 2010; Brandt et al., 2010). In recent years, studies were focused on analysis of the most frequently cited articles in a field to examine the characteristics of the field, emergency medicine (Tsai et al., 2006), obstetrics and gynecology (Brandt et al., 2010), rehabilitation (Shadgan et al., 2010), ophthalmology (Ohba et al., 2007), and orthopedics (Lefaivre et al., 2011).

Institute for Scientific Information (ISI) was founded by Eugene Grafield. The institute has been collecting citation and other academic impact information since 1945 which has been available electronically

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since 1979 (Science-Thomas Reuters, 2010). The database contains citation data for more than 11,000 research journals (Web of Knowledge, 2009) not only from the field of science and social sciences but also from arts and humanities. Institute for Scientific Information now merged in Thomson Reuters Web of Science database calls their newest journal citation system "Science Citation Index Expanded (SCI-Expanded)" and it is one of the databases available under the banner of Web of Science (Science-Thomas Reuters, 2010).

The aim of this study was to identify the top-cited articles published, countries of origin, and top productive institutions in the field of environmental science.

2. Methodology

The environmental science documents reported in this study were derived from the Thomson Reuters Web of Science database which is based on the online version of SCI-Expanded. According to JCR of 2009, it indexes 7387 journals with citation references across 174 scientific disciplines. Among them 181 journals publish articles listed in environmental sciences category indexed by ISI in 2009. The only document type considered was article. The citation frequencies for each of the top-cited articles per year were collected since an article was published to 2010. The total number of times article cited in 2010 was recorded as C2010 and the total number of times article cited from its publication to 2010 was recorded as TC2010. The articles with TC2010 > 500 were selected as top-cited articles. The records were downloaded into spreadsheet software, and additional coding was manually performed using Excel to obtain the frequency distributions and percentages. Articles originating from England, Scotland, Northern Ireland, and Wales were reclassified as being from the United Kingdom (UK). Articles originating from Federal Republic of Germany, German Democratic Republic, and Germany were reclassified as being from Germany. Collaboration type was determined by the addresses of the authors, whereas, the term "independent country article" was assigned if the researchers' addresses were from the same country. The term "internationally collaborative article" was designated to those articles that were coauthored by researchers from multiple countries (Chiu and Ho, 2005). The term "independent institution article" was assigned if the researchers' addresses were from the same institution. The term "inter-institutionally collaborative article" was assigned if authors were from different institutions (Li and Ho, 2008).

3. Results and discussion

3.1. Effect of time on citation analysis

Citation analysis provides quantitative information about the authors, areas of research and journals. This information is useful to identify classic works and high-impact journals (Dubin et al., 1993). The article that surpasses a threshold of 100 citation numbers is termed as "classic article". Table 1 presents articles in environmental science cited for more than 1000 times from publication date to 2010. Out of these twelve articles, six (50%) were published in between 1975 and 1985, two (17%) between 1985 and 1995, and four (33%) were published in between 1995 and 2005. The journals in which these articles published were *Water Resources Research* (three articles), *Environmental Science and Technology* (two articles), *Remote Sensing of Environment* (two articles), *Ecological Applications* (two articles), *Water Research* (one article), *Conservation Biology* (one article), and *Environmental Conservation* (one article). A highly cited article (TC2010 = 1806) among them was published in *Environmental Science and Technology* in 2002, while *Water Resources Research* have most of the top-cited articles listed. The high citation count measures the impact of scientific work, utility and scientific activity. The second highly cited article (TC2010 = 1675) was published in *Water Resource Research* in 1980 and an article with least citations (TC2010 = 1011) was published in 1998. The "time effect" for these top cited articles was demonstrated in Figs. 1 and 2. "Time effect" is one of the shortcomings of citation analysis. According to this shortcoming the recent most articles being at disadvantage (Lefaivre et al., 2011). As seen in Fig. 1, since year 2005, Kolpin et al. (2002) gains highest number of citations compared to other top-cited articles. While, since 2008, Holben et al. (1998) is the second highly cited article, though it is at the bottom among the top-cited articles. Karickhoff et al. (1979) was spotted third among the citation list though it had gained least number of citations since 2004. This shows an apparent role that time plays from the year of publication. Despite of improvement in research quality with the advancements in analyzing techniques and improvement in experimental setups, recently published articles are on the back seat in terms of citation analysis.

Table 1
The most frequently cited articles (TC2010 > 1000) in environmental science.

Rank	Citation information	TC2010
1	Kolpin, D.W., Furlong, E.T., Meyer, M.T., Thurman, E.M., Zaugg, S.D., Barber, L.B. and Buxton, H.T. (2002), Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999–2000: a national reconnaissance. *Environmental Science & Technology*, **36** (6), 1202–1211.	1806
2	Topp, G.C., Davis, J.L. and Annan, A.P. (1980), Electromagnetic determination of soil water content: measurements in coaxial transmission lines. *Water Resources Research*, **16** (3), 574–582.	1675
3	Karickhoff, S.W. Brown, D.S. and Scott, T.A. (1979), Sorption of hydrophobic pollutants on natural sediments. *Water Research*, **13** (3), 241–248.	1660
4	Mualem, Y. (1976), New model for predicting hydraulic conductivity of unsaturated porous media. *Water Resources Research*, **12** (3), 513–522.	1648
5	Saunders, D.A., Hobbs, R.J. and Margules, C.R. (1991), Biological consequences of ecosystem fragmentation: a review. *Conservation Biology*, **5** (1), 18–32.	1456
6	Tucker, C.J. (1979), Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, **8** (2), 127–150.	1375
7	Holben, B.N., Eck, T.F., Slutsker, I., Tanre, D., Buis, J.P., Setzer, A., Vermote, E., Reagan, J.A., Kaufman, Y.J., Nakajima, T., Lavenu, F., Jankowiak, I. and Smirnov, A. (1998), AERONET — a federated instrument network and data archive for aerosol characterization. *Remote Sensing of Environment*, **66** (1), 1–16.	1351
8	Gorham, E. (1991), Northern peatlands — role in the carbon-cycle and probable responses to climatic warming. *Ecological Applications*, **1** (2), 182–195.	1077
9	Fielding, A.H. and Bell, J.F. (1997), A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation*, **24** (1), 38–49.	1063
10	Hamilton, M.A., Russo, R.C. and Thurston, R.V. (1977), Trimmed spearman-karber method for estimating median lethal concentrations in toxicity bioassays. *Environmental Science & Technology*, **11** (7), 714–719.	1030
11	Beven, K. and Germann, P. (1982), Macropores and water-flow in soils. *Water Resources Research*, **18** (5), 1311–1325.	1015
12	Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N. and Smith, V.H. (1998), Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications*, **8** (3), 559–568.	1011

TC2010: number of citations till 2010.

3.2. Distribution of top-cited articles

The articles published in environmental science from 1899 to 2010 were searched. The statistical overview showed that in between 1971 and 2002, 88 top-cited articles in environmental science were published (Fig. 3). The first top citied article appeared in 1971 and last one was published in 2002. The relation between the time and numbers of top articles was not significant. It was accepted that citation analysis penalizes recent articles because a paper takes time to receive citations. However, there is no statistically significant correlation between time and the most cited articles (O'Leary, 2009).

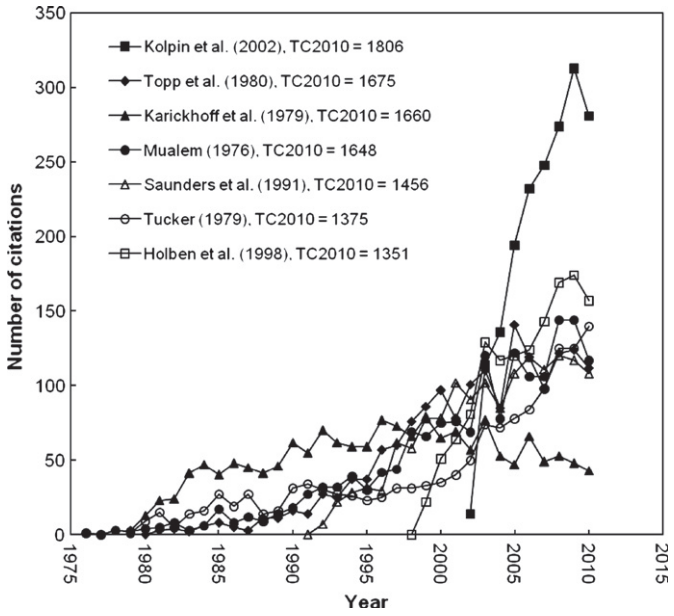

Fig. 1. Top-cited articles in environmental science (TC2010 > 1300).

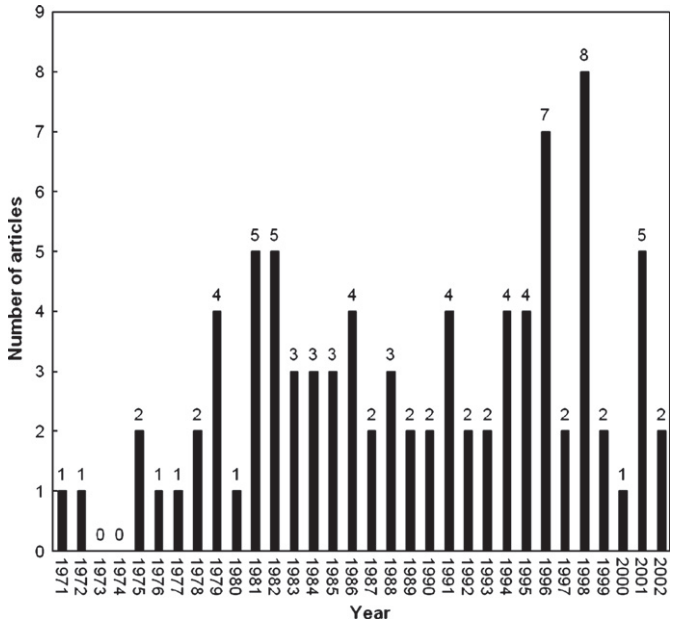

Fig. 3. Distribution of top-cited articles.

On an average two top-cited articles per year were published during this time slot. In a year 1998, eight top-cited articles were published. While in 1996 the published articles were seven. For two consecutive years i.e. 1973 and 1974, no article appeared under these considerations.

According to JCR of 2009, it indexes 181 journals listed in the category of environmental sciences. The 88 top-cited articles published in 26 different journals are listed in environmental sciences category (Expended Table). *Environmental Science & Technology* was ranked first with 25 (28%) top-cited articles. *Water Resources Research* was ranked second with 13 (15%) articles, followed by *Water Research* with seven articles, *Environmental Health Perspectives* with six articles, *Remote Sensing of Environment* with five articles and *Environmental Management* with two articles. Moreover, *Ozone-Science & Engineering*, *Environmental Conservation*, *Radiation and Environmental Biophysics*, *Journal of the Air & Waste Management Association* and *International Journal of Environmental Analytical Chemistry* published one top cited article each.

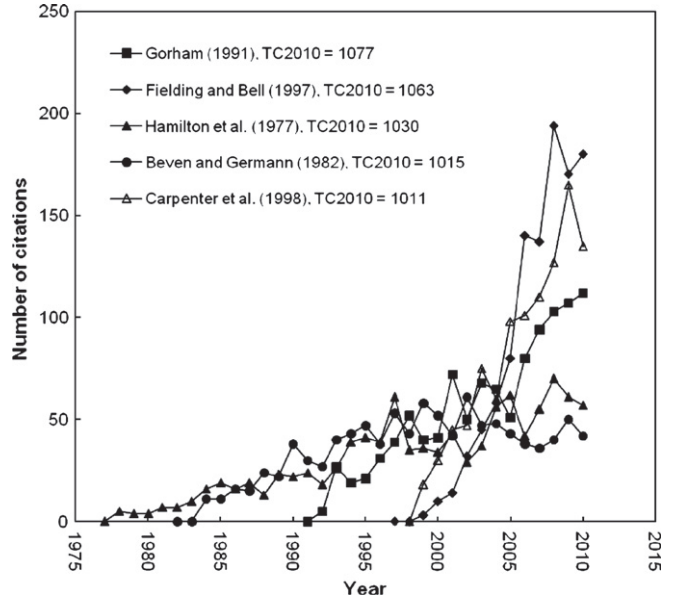

Fig. 2. Top-cited articles in environmental science (1300 > TC2010 > 1000).

3.3. Publication performances: countries and institutions

The contributions provided by different countries/territories were estimated by focusing on the location of the affiliation of at least one author of the top articles. The countries were ranked according to the number of total top articles published with their affiliations (Table 2). This includes the number of articles (TP) and percentage of total articles (TPR (%)), single country articles (SPR (%)), internationally collaborative articles (CPR (%)), first author articles (FPR (%)), and corresponding author's articles (RPR (%)). Also considered were the percentage of independent articles in total top articles for each country (S%). There were two articles without authors address information on the Web of Science. Of all the articles with author's addresses, 77 (90%) were SPR (%) and 9 (10%) were CPR (%). The data presents the United States of America (USA) as the most productive country with 57 top articles, followed by the United Kingdom (UK) and Canada with eleven and seven top articles, respectively. This shows the overwhelming influence of the USA in the field of environmental sciences. The productivity of second most dominating country

Table 2
Countries of top-cited articles.

Country	TP	TPR (%)	SPR (%)	CPR (%)	FPR (%)	RPR (%)	S%
USA	57	1 (66)	1 (64)	1 (89)	1 (60)	1 (64)	86
UK	11	2 (13)	2 (12)	3 (22)	2 (12)	2 (13)	82
Canada	7	3 (8.1)	4 (5.2)	2 (33)	3 (5.8)	4 (4.3)	57
Switzerland	5	4 (5.8)	3 (6.5)	N/A	3 (5.8)	4 (4.3)	100
Germany	5	4 (5.8)	5 (3.9)	3 (22)	3 (5.8)	3 (5.8)	60
Japan	2	6 (2.3)	6 (1.3)	6 (11)	7 (1.2)	6 (1.4)	50
Spain	2	6 (2.3)	6 (1.3)	6 (11)	6 (2.3)	6 (1.4)	50
Brazil	2	6 (2.3)	N/A	3 (22)	N/A	N/A	0
Israel	1	9 (1.2)	6 (1.3)	N/A	7 (1.2)	N/A	100
Australia	1	9 (1.2)	6 (1.3)	N/A	7 (1.2)	6 (1.4)	100
Denmark	1	9 (1.2)	6 (1.3)	N/A	7 (1.2)	6 (1.4)	100
Hong Kong	1	9 (1.2)	6 (1.3)	N/A	7 (1.2)	6 (1.4)	100
Netherlands	1	9 (1.2)	6 (1.3)	N/A	7 (1.2)	6 (1.4)	100
France	1	9 (1.2)	N/A	6 (11)	N/A	N/A	0
Norway	1	9 (1.2)	N/A	6 (11)	7 (1.2)	N/A	0
Sweden	1	9 (1.2)	N/A	6 (11)	N/A	N/A	0

TP: total number of articles; TPR (%), SPR (%), CPR (%), FPR (%), and RPR (%): the rank and percentage of total articles, single country articles, internationally collaborative articles, first author articles, and corresponding author articles in their total articles, respectively; S%: the percentage of single country articles among total articles for each country; N/A: not available.

was about one-fifth compared to the top competitor. There are several reasons behind this dominance. Large girth of American research, their higher research budgets might be some of the possible reasons. Citing American articles, favoring American journals to publish their research, and preference of American reviewers to accept American articles might be some of the other reasons for their dominance in the field (Campbell, 1990; Link, 1998). The percentage of single country articles for each country was highest for Switzerland, Israel, Australia, Denmark, Hong Kong, and Netherlands while for the USA this was 86%.

The contribution of different institutions was estimated by its affiliation of at least one author of the top articles. Eighty-six articles with the author's address information on the Web of Science were analyzed. Fifty-six (65%) articles were single institution publications and 30 (35%) were inter-institutionally collaborative publications. The top ten institutions were ranked by their number of total top articles. This includes the number and percentage of single institution articles and inter-institutionally collaborative articles. Also, considered were first author articles and corresponding author articles (Table 3). Out of the top ten most productive institutions eight are affiliated to the USA and the other two are from the UK and Switzerland, respectively. The U.S. Geological Survey in the USA is the most productive institution. Brunel University, UK had the lowest percentage of single institution articles in their total top articles (S%) while, University of Minnesota, USA and Swiss Federal Institute of Technology, Switzerland have 100% of single institution articles.

3.4. Article life span

The article citation usually follows a time course. The article's life span demonstrates the influence of article on the scientific research. Fifty-three top articles (60%) have no citations, 15 (17%) articles have one citation, and 8 (9.1%) articles have two citations during the year of publication. We had observed article life span for thirteen top articles having higher citations in 2010 (C2010 > 100) in environmental science. It was found that seven articles received no citations during the year of publication (Figs. 4 and 5) while, Kolpin et al. (2002) had received fourteen citations during the year of publication. This is the highest among the top articles list. The average citations were calculated for initial five years ever since the year of top articles publication. Kolpin et al. (2002) received 138 citations followed by Gordon (2001), Holben et al. (1998), and Desbrow et al. (1998) with 69, 44, and 41 citations, respectively. The maximum number of citations Mualem (1976) received for two consecutive years i.e. 2008–09 was 144, though the article was published in 1976. This demonstrates the active influence of scientific work (either positively or negatively) on the ongoing research. All these top-cited articles showed 100 or above yearly citations in between 2001 and 2010. The maximum numbers of citations (313) were received by Kolpin et al. (2002) in 2009.

In-depth analysis of the works reported in these top articles showed their respective concern toward the individual research area. The most cited article by Kolpin et al. (2002) did a nationwide survey in US (139 stream sampling sites) to detect the occurrence of pharmaceuticals, hormones and other organic wastewater contaminants in water streams. They had developed five analytical laboratory methods for detecting and determining veterinary and human antibiotics, prescription and non-prescription drugs, steroids and hormones and many other organic waste related compounds. The reported methods were effective for determining these contaminants even in traces. Various researchers have adopted their methods as a reference during their respective studies. This highlights the quality and importance of their work for a particular research area. A review article on prediction error by Fielding and Bell (1997) is the second most cited article. The review covers nature and measurement of prediction errors. They introduced normalized mutual information (NMI) to ecology used in species distribution models (SDM). An article by Holben et al. (1998) on utilization of aerosol robotic network (AERONET) by National Aeronautics and Space Administration (NASA) for monitoring and characterization of aerosols is the third most cited article. The AERONET is a system of globally-distributed autonomous sun-photometers established in early 1990s to support atmospheric studies at various scales through standardized measurements of the direct sun irradiance and sky-radiance. The article covers operational aspects of the monitoring system, the precision and accuracy of the measuring radiometers, a brief description of the processing system, and the access to the database. Article life curves (Fig. 4) clearly demonstrate the influence of these articles on scientific research. An article on vegetation monitoring was published in 1979 by Tucker (Tucker, 1979). The study evaluates and quantifies the relationships between various linear and combinations of red and photographic infrared radiances and experimental plot biomass, leaf water, and chlorophyll content. The studies conclude that the sensors with spectral bands in red and near infra-red lend themselves well to vegetation monitoring as the difference between the red and near infra-red bands has been shown to be a strong indicator of the amount of photosynthetically active green biomass. Since last eight years the citations of this article suddenly increases showing the influence of the work on present research. An article on non-point pollution of surface water by phosphorus and nitrogen was published by Carpenter et al. (1998). The authors observed agricultural and urban activities along with atmospheric depositions as the major contributors of non-point pollution of surface water. They suggested site-specific analysis to monitor and control this pollution. Study concludes that reducing surplus flow of nutrients in agricultural practices, agricultural and urban runoff, and nitrogen emissions from fossil fuel burning could be an effective way to control it. Ternes investigated the occurrence of drug residue belonging to different medicinal classes in German municipal sewage treatment plant discharges, rivers and stream waters (Ternes, 1998). Similar to Ternes's work Halling-Sorensen and co-workers presents an overview on existing knowledge of the exposures, fates, and effects of medical substances on the environment (Halling-Sorensen et al., 1998). They also discussed this knowledge in

Table 3
Top-ten most productive institutions.

Institution	TP	TPR (%)	SPR (%)	CPR (%)	FPR (%)	RPR (%)	S%
U.S. Geological Survey, USA	6	1 (7.0)	1 (8.9)	13 (3.3)	1 (7.0)	2 (7.2)	83
Brunel University, UK	6	1 (7.0)	11 (1.8)	1 (17)	2 (4.7)	1 (8.7)	17
U.S. Environmental Protection Agency (EPA), USA	5	3 (5.8)	2 (5.4)	2 (6.7)	2 (4.7)	7 (2.9)	60
University of Arizona, USA	4	4 (4.7)	5 (3.6)	2 (6.7)	4 (3.5)	3 (4.3)	50
Oregon State University, USA	4	4 (4.7)	5 (3.6)	2 (6.7)	7 (2.3)	7 (2.9)	50
University of Minnesota, USA	3	6 (3.5)	2 (5.4)	N/A	4 (3.5)	3 (4.3)	100
Swiss Federal Institute of Technology, Switzerland	3	6 (3.5)	2 (5.4)	N/A	4 (3.5)	7 (2.9)	100
Cornell University, USA	3	6 (3.5)	5 (3.6)	13 (3.3)	7 (2.3)	13 (1.4)	67
National Aeronautics and Space Administration (NASA), USA	3	6 (3.5)	11 (1.8)	2 (6.7)	7 (2.3)	3 (4.3)	33
University of Virginia, USA	3	6 (3.5)	11 (1.8)	2 (6.7)	16 (1.2)	3 (4.3)	33

TP: total number of articles; TPR (%), SPR (%), CPR (%), FPR (%), and RPR (%): the rank and percentage of total articles, single institution articles, inter-institutionally collaborative articles, first author articles, and corresponding author articles in their total articles, respectively; S%: the percentage of single institution articles among total articles for each institution; N/A: not available.

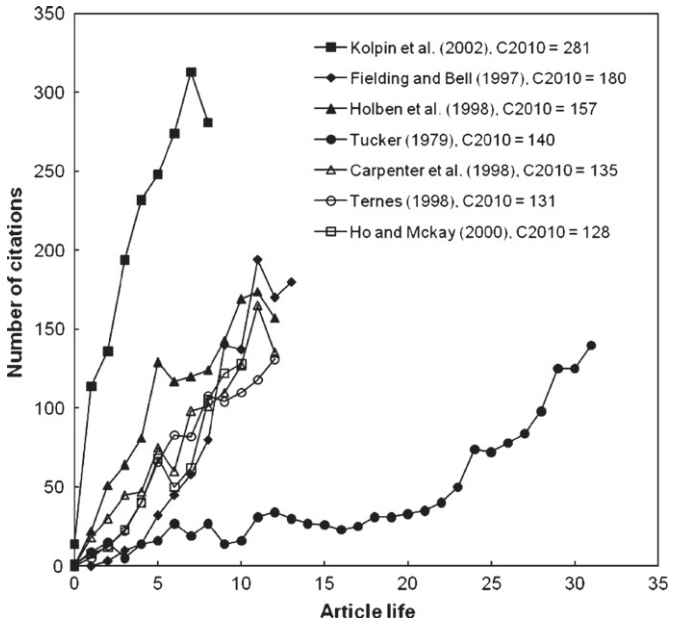

Fig. 4. Article life of top articles (C2010 > 120).

context of the proposed European Union directives on environmental risk assessment of both veterinary and human medical substances. Increase in citations in recent time clearly demonstrates the importance of their respective works in present scenario. Mualem developed a new model for predicting hydraulic conductivity of unsaturated porous media and observed its applicability on 45 soil samples (Mualem, 1976). The model predicts the unsaturated hydraulic conductivity curves by using the moisture content capillary head curve and measured value of the hydraulic conductivity at saturation. Soil water content was determined electromagnetically (Topp et al., 1980). Article's life analysis showed uniform increase in the citations. A research article on development of pseudo-second-order kinetics rate equation was published by Ho and McKay (1999). They had applied this model on the adsorption of divalent metal ions on sphagnum moss peat under various experimental conditions. The citation analysis shows continuous increase in citations as this is one of the most common models applied to kinetics data

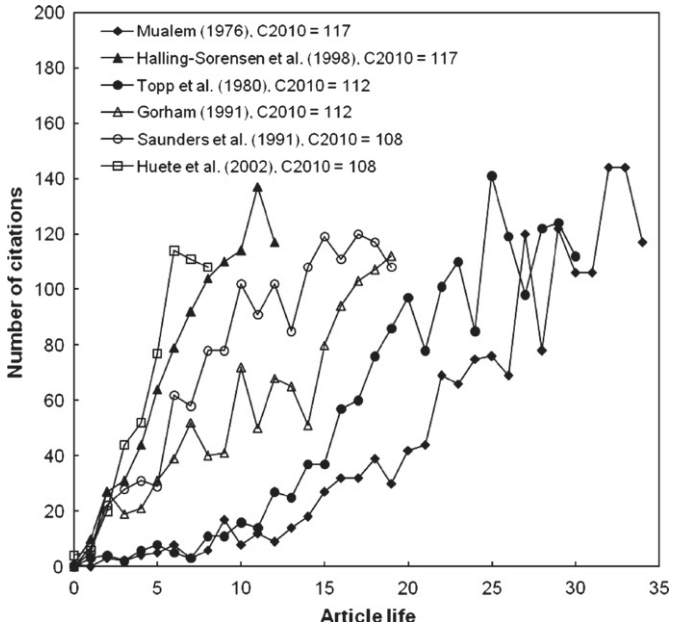

Fig. 5. Article life of top articles (120 > C2010 > 100).

predicting the nature of adsorption process (chemical or physical adsorption). Review articles by Gorham (1991) and Saunders et al. (1991) published way back in 1991 achieved considerable number of citations during the studied time period. An overview on role in carbon cycle and its probable responses to global climate warming was given by Gorham while, various biological consequences of ecosystem fragmentation were reviewed by Saunders and coworkers. Saunders's article achieved more than hundred citations for the last six consecutive years.

3.5. Demerits of citation analysis

The citation analysis provides a good tool to judge the research quality to a great extent but still it suffers from certain limitations that are to be addressed. Environmental science involves crossover into multiple research fields such as geology, chemistry, environmental engineering, and life science. This leads to our target articles that appear in core journals related to chemistry, geology or environmental engineering, revealing one of the limitations of this analysis as we had used Web of Knowledge database for retrieving environmental science journals as the source of top articles. The articles with maximum number of citations have been displayed without correlating the age factor. As observed from the data majority of articles were published in between 1975 and 1985 showing favor for older articles. Citing high impact journals, self-citations, incomplete citing and omission bias are some of the other demerits (Hennessey et al., 2009). Favoring native language article is also one of the demerits of citation analysis. There are some landmark articles that are not frequently cited as their findings becomes well known and this is termed as obliteration by incorporation (Brandt et al., 2010) which is also a demerit of this analysis. The analysis is only quantitative, providing no idea about the qualitative aspects of citations.

4. Conclusions

The results of this study demonstrate highly cited articles with their yearly citations. This study also highlights the top productive institutions and countries. We had also observed that this analysis could not be considered as a direct measure of the impact or importance of a particular scholarly work but rather provides a marker of its recognition within the scientific community. There are some implementations that are required to improve this analysis. There should be a method to judge and distinguish between positive and negative citations. There should be some method that will avoid bias citation analysis between new and old articles.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2012.05.035.

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