Tersedia online di: http://ejournal.undip.ac.id/index.php/teknik

TEKNIK, 43 (3), 2022, 296-303

Water Resource Management in Developing Countries: Synthesizing the Literature

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Abstract

The literature on water management is extensive, yet most publications have been concerned with the context of the developed world and much less with the developing context. This study aims to examine the extant research, provide an overview of the empirical research in the field of water resource management in a developing context, and provide several future research suggestions. To perform this analysis, we use R and Scimeetr to compile the resources and visualize the result systematically. The raw data were then reviewed and analyzed further. We find evidence that the field of water resource management in a developing-world context is presently divided into five major themes: water resources, water quality, water management, sustainability, and climate change. We find evidence, too, that most literature in the field of water resource management in developing contexts ironically came from developed countries, such as the United States (265), the United Kingdom (128), and China (98). It is expected that this study could be used as a stepping stone to move the literature on water resource management, particularly in the developing world, forward.

Keywords: *water resources; water management; developing world; sustainability; review*

1. Introduction

As renewable resources, water availability is inconsistent and fairly limited (Pimentel et al., 1994). Almost every country globally experiences water shortages and suffers rather seriously (Falkenmark & Lindh, 1993; Gleick, 1993). The problem is becoming more severe in the context of emerging countries. Clean water resources per capita, as the population increase significantly, are sharply declining (Pimentel et al., 1997). The quality of the water is also deteriorating rather quickly.

In the era of globalization and 'virtual water,' there is a need to bring along international flows of virtual water. However, developing countries can only achieve their development goals if they rely on their resources (Hoekstra & Hung, 2005). Thus, developing countries need a solid policy framework and economically sound water pricing to help them manage their water resources appropriately.

While water resource management is important vis-à-vis Sustainable Development Goals, the literature focusing on developing countries' context remains limited and ambiguous. It appears that literature in this field is currently developing with limited attention from civil engineering and water management scholars. In particular, most literature currently focuses on poor communities and neglects those rapidly developing countries (Ujang & Buckley, (2002).

Thematic evolution analysis, cluster analysis, and SciMAT were used to identify the evolutionary path of water resource management. This study proposed that issues related to scale, strengthening communication and integration within disciplines, introducing new theories and methods, and sustainable use will become future research directions that require more water resource management attention (Tiangui et al., 2021).

A well-defined holistic agenda is required to improve water resources and regulated usage for developing countries. Integrated approaches such as building the water balance over usage (groundwater recharge and runoff harvest), regulated use (sensitive and need-based usage through public awareness), and promotion of multiple uses (wastewater treatment and reuse of treated water) of water could improve the water value and productivity in developing countries (Hanamant, 2022).

Such "mechanical" approach is also suggested, particularly for areas still considered new and emerging,

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doi: 10.14710/teknik.v43i3.46499

and that typically has not been the focus of previous studies in the literature (Iman, 2020).

Based on the author's search, the author has yet to find any similar research with the same method as this research. This paper aims to analyze the extant literature on water resource management, especially in the context of the developing world. Our contribution is as follows. First, we want to fill the gap by examining water resource management in the context of rapidly developing countries. Second, we provide a theoretical contribution toward water management and, more importantly, shed light on a policy framework that better suits emerging countries.

In doing so, the paper is organized as follows. Section 1 provides the introductory, aim, purpose, and contribution of this paper. While section 2 elaborates on our approach and methodology used in this paper. Section 3 discusses our data and our initial findings from the literature. We also critically examine our findings and discusses them with the extant literature on water resource management. The last section concludes and provides several contributions and further research avenues.

2. Research Method

This study reviews the extant literature, critically asses those studies, and synthesizes the quantitative and qualitative findings. Thus, to answer the research question mentioned earlier, we began conducting our search in January 2020. We use R statistical software and Scimeetr (https://github.com/MaximeRivest/scimeetr) open-source package to help us review the extant literature more robustly and thoroughly.

We first load bibliometric data into R. We searched in Scopus Elsevier using the keywords "water resource management developing countries" within the article title, abstract, and keyword. We ended up with 3,294 document results. We then limited our search to peer-reviewed journals/articles and ended up with 2,221 documents. We export the result into *.csv files to be analyzed further in R.

This approach is rigorous and relevant since we established our corpus from a reputable database and excluded both predatory publications as well as grey literature. Such a "mechanical" approach is also suggested, particularly for areas still considered new and emerging, and that typically has not been the focus of previous studies in the literature (Iman, 2020).

We then design a visualization of peer-reviewed papers by establishing various networks. This is particularly important to create a conceptual mapping of the literature in the context of water resource management. We also attempt to find research communities related to this field and characterize those research communities accordingly. Lastly, we also generate a relevant reading list for further research avenues.

In the following section, this article will provide a tentative overview of water resource management in a developing context, organized around several important topics in the corpus. The observed result and our analysis will be discussed below.

Table 1. The 10 most mentioned keywords

No	Keyword	Frequency
1	developing countries	83
2	climate change	68
3	water resources	57
4	sustainability	45
5	water quality	44
6	water management	42
7	sustainable development	41
8	irrigation	39
9	water	34
10	water resources management	33

3. Results and Discussion

Of the paper that we analyze, on average, each paper cites 25 elements. Our data set itself cites 45,702 different elements. We divided the total citation per paper into the following quantiles: 0% = 1; 25% = 3; 50% = 8; 75% = 21; 100% = 1,072. From those quantiles, we can interpret that in this particular epistemic community, 75% of the publications were cited less than 21 times, 50% were cited less than 8 times, and 25% were cited less than 3 times. There are, however, several articles that were cited up to 1,072 times.

Table 2. The 10 most productive journal

No	Journal Name	Frequency
1	International Journal of Water Resources Development	84
2	Water Science and Technology	45
3	Water Resources Management	43
4	Water International	38
5	Journal of Environmental Management	34
6	Science of the Total Environment	34
7	Environmental Monitoring and Assessment	30
8	Water (Switzerland)	28
9	Natural Resources Forum	23
10	Environmental Management	22

doi: 10.14710/teknik.v43i3.46499

Table 3. The most discriminant keywords in the dataset

No	Keyword	ID & DE	DE	ID
1	developing countries	952	83	869
2	climate change	294	68	226
3	water resources	450	57	393
4	sustainability	159	45	114
5	water quality	435	44	391
6	water management	948	42	906

Departing from there, we then calculate the mean number of literature citations in the water resource management field, especially in developing contexts. The mean number of citations per publication here is 21.54302. This number is almost three times the median (8), indicating that most publications in this field were cited only a few times, and only a limited number of articles were profusely cited. We also found that papers in our dataset are cited on average once per year.

Listed in Table 1, we can conclude that this research community focuses on developing countries, climate change, water resources, sustainability, and water quality. Those keywords and journal frequencies indicate the theme of the scientific community. Similarly, as can be verified from Table 2, the literatures on this particular topic are dominated by the International Journal of Water Resources Development. It was followed by other journals such as Water Science and Technology, Water Resources Management, and Water International, among others.

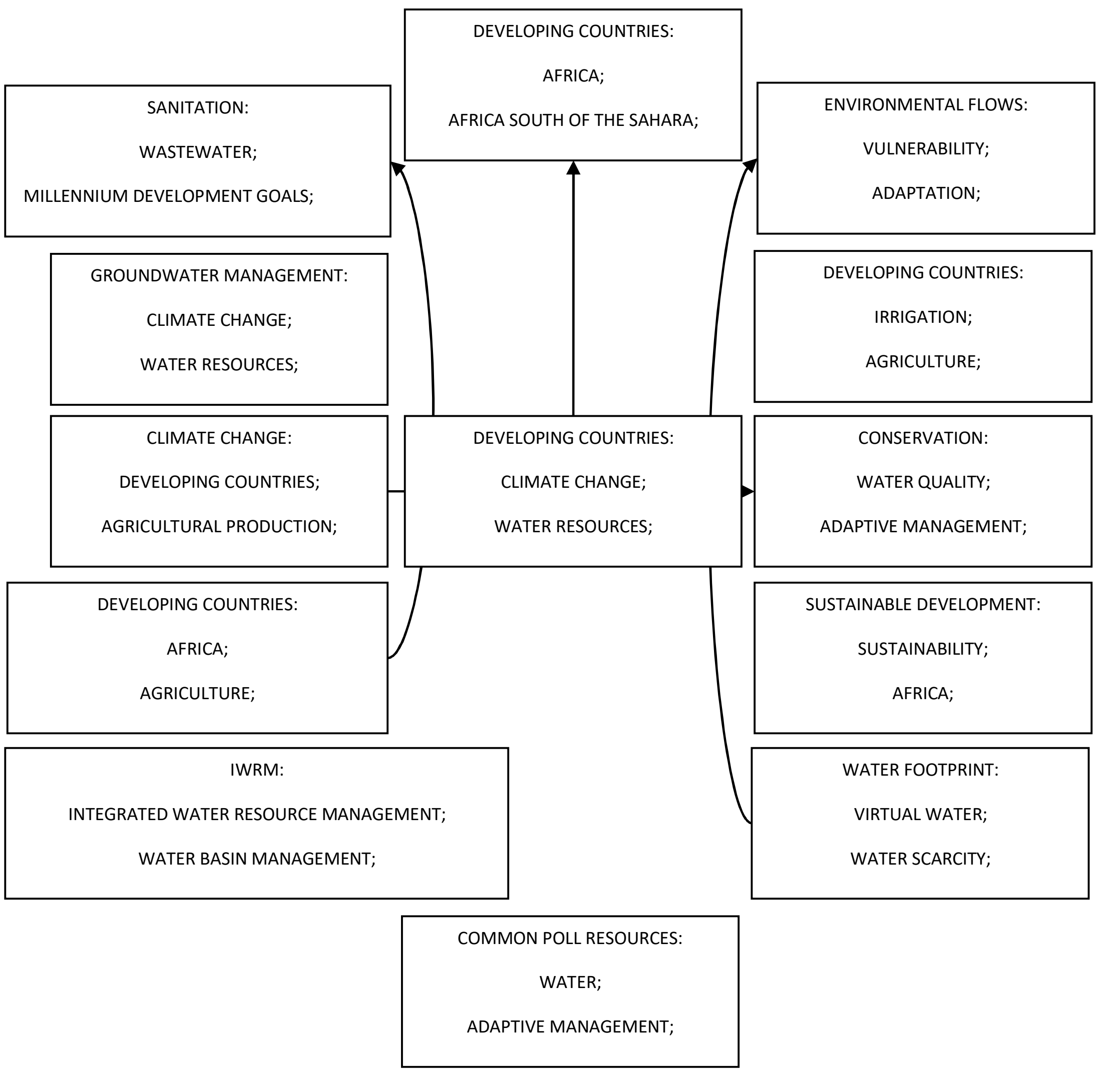

Fig. 1. Clustering characteristics of the scientific community

doi: 10.14710/teknik.v43i3.46499

Table 4. Main reading list in the community

No	Seminal Articles/Papers	Metric
1	Ostrom E, 1990, Governing Commons, N/A, N/A	32
2	N/A, 2005, Ecosystems Human Well, N/A, N/A	19
3	Biswas AK, 2004, Water Int, 29, 248	15
4	N/A, 1987, Our Common Future, N/A, N/A	15

Table 5. Most popular journal in the community

No	Journal Name	Citations	H-index	Impact Factor	Papers Cited	Paper Within
1	Natural Resources Forum	36	5	3	12	NA
2	Nature	90	5	3.46	26	3
3	Science	145	5	3.22	45	NA
4	Water Resources	249	4	2.44	106	NA
5	Water International	74	4	2.96	25	38
6	Water Policy	87	4	2.56	34	17

Table 6. Most prolific authors in the field

No	Author	HHL	HH	HL	H	Local Citation	Global Citation	NB Papers	NB Highly Cited
1	Mihelcic, J.R.	2	6	2	7	4	306	9	2
2	Abeysuriya, K.	1	1	1	1	2	17	1	1
3	Batchelor, C.	1	2	1	2	3	77	2	1
4	Butterworth, J.	1	1	1	1	3	68	1	1
5	Calzada, J.	1	1	1	1	2	5	1	1
6	Falk, T.	1	1	1	1	2	21	1	1

Furthermore, the most discriminant keywords in our dataset are "developing countries," "climate change," "water resources," "sustainability," "water quality," and "water management." To get more detailed information regarding the corpus of publication we analyze, we can characterize further by generating a list of data frames, with a single data frame per epistemic community (presented in Table 3). The first two columns of the table explain the keywords, while the consecutive columns contain the frequency of the notable keywords (i.e., the number of publications that uses this keyword).

Concurrently, we then draw a map of the scientific community and map each cluster to identify their characteristics on their own. This is important to get an overarching view of the literature on water resources management in the context of developing countries. We can identify each community constituting the main community by analyzing the discriminant keywords. The graphical representation of those sub-communities can be seen in Figure 1.

Concomitantly, we have to characterize the main epistemic research community and observe which scientific community it is constituted. We then can analyze the default reading list of each community. As presented in Table 4, the most popular literature on the reading list is Ostrom (Ostrom, 1990), with 32 metric scores. This was followed by Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) report with a 19 metric score, Biswas (Biswas, 2004) and The Brundtland Report by the UN’s World Commission on Environment and Development (United Nations World Commission on Environment and Development, 1987) – both with 15 metric scores.

We also establish a list of data frames, a single data frame per community, to identify the journals' names themselves. We want to know which journals and/or publishers publish articles most on water resources management in developing countries. Table 5 lists our findings, along with some publication-based metrics. At the top of the list is Natural Resources Forum, followed by Nature, Science, Water Resources, Water International, and Water Policy.

Similarly, we can also analyze author publishing in this field. The first two columns of these data frames describe the author names, followed by several author-based metrics (verified in Table 6). The first on our list is James R. Mihelcic (University of South Florida), followed by Kumi Abeysuriya (University of Technology Sydney), Charles Batchelor and John Butterworth (IRC International Water and Sanitation Centre), Joan Calzada (Universitat de Barcelona), as well as Thomas Falk (Institute for Co-operation in Developing Countries).

doi: 10.14710/teknik.v43i3.46499

Table 7. Expert in the community

No	Publication	Metric
1	Hanasaki N, 2013, Hydrol Earth Syst Sci, 17, 2393	3.019877
2	Mihelcic JR, 2006, Environ Eng Sci, 23, 426	2.833333
3	Mihelcic JR, 2011, Chemosphere, 84, 832	2.833333
4	Butterworth J, 2010, Water Altern, 3, 68	2.833333
5	Cornejo PK, 2013, J Environ Manage, 131, 7	2.000000
6	Naughton CC, 2018, Environ Sci Technol, 52, 11803	2.000000
7	Orner KD, 2017, Waterlines, 36, 167	2.000000
8	Ouedraogo FR, 2016, Water Res, 99, 253	2.000000
9	Verbyla ME, 2013, Environ Sci Technol, 47, 3598	2.000000
10	Verbyla ME, 2016, Environ Sci Technol, 50, 6803	2.000000
11	Verbyla ME, 2016, Sci Total Environ, 551-552, 429	2.000000

Table 8. Papers with high betweenness

No	Publication	Metric (betweenness)
1	Nigussie Y, 2018, Ecol Econ, 151, 142	0.011249869
2	Nazari B, 2018, Agric Water Manage, 208, 7	0.010283921
3	Rai PK, 2012, Environ Monit Assess, 184, 421	0.010100646
4	Fan J-L, 2019, Ecol Model, 392, 128	0.008078113
5	Phan TD, 2018, J Clean Prod, 183, 940	0.008033046

Table 9. Papers with high connectedness

No	Publication	Metric (connectedness)
1	Madad A, 2020, Ecol Econ, 169	1095
2	Roekmi RAK, 2018, Nat Resour Forum, 42, 108	68
3	Madrigal-Ballestero R, 2015, J Water Clim Change, 6, 831	68
4	Balana BB, 2011, J Environ Manage, 92, 2634	59
5	[no author name available], 2006, IAHS-AISH Publ, 1	56

Table 10. Papers that cite most other papers

No	Publication	Metric (cite most others)
1	Chikozho C, 2017, 100, 363	2
2	Machado AVM, 2019, Water, 11	2
3	Baguma D, 2012, Water Policy, 14, 977	1
4	Bai M, 2017, Water, 9	1
5	Carpenter S, 2017, Nat Resour J, 57, 101	1

To get into a more detailed analysis of the literature, we categorize experts in this field by examining the author's information from our data set. Experts within an epistemic community were identified according to the number of publications in the field of water resources management in developing countries. They measured the number of times each of their publication was cited.

Table 11. Country of origin of the literature

No	Country of Origin	Count
1	N/A	323
2	United States	265
3	India	146
4	United Kingdom	128
5	China	98
6	Africa	66

We thus rank the authors based on their harmonic local H-index. The H-index could indicate the author's impact and productivity in his/her field. For instance, a 9 H-index means that an author has published at least 9 articles with 9 or more citations for each. Moreover, a local H-index describes the impact of an author in his/her community – only citations from articles in the relevant epistemic community were counted. Similarly, a harmonic local H-index represents the number in which the authors do not obtain full credit for the

doi: 10.14710/teknik.v43i3.46499

citation they received.[1] The result of this calculation can be seen in Appendix.

We also generate a list of publications for which many scholars are considered experts in water resource management in developing countries. In order to get the number, every author is assigned a harmonic local H-index. Measurement of a weighted sum of the harmonic-local-H-index of each author was then done. The result was verified in Table 7.

From there, we then calculate the betweenness and connectedness of such an author. Betweenness represents the importance of an article in connecting two clusters of publications. Therefore, articles with a high betweenness would be more interdisciplinary (presented in Table 8). On the other hand, connectedness represents the number of links an article has. Therefore, articles with a high connectedness have cited what most other research cited. The result of this calculation can be verified in Table 9.

Lastly, we wanted to identify papers that cite most other papers in the context of water resource management in developing countries that can be obtained. This is indeed not a centrality measure instead. This observation is based on the articles' connection to each other. This number also indicates that the paper finds literature reviews and relatively newer papers that have an especially good grasp on the field of water resource management, especially in the context of developing countries. The result of this calculation is verified in Table 10.

4. Conclusion

This paper analyzes the extant literature on water resource management, particularly in the context of emerging countries. This article provides an understanding of the literature in this field and identifies the main publication outlet and expert in the area. Unlike our earlier prediction, there is much literature in the water resource management field in developing countries. We find evidence that this field is divided into five major themes: water resources, water quality, water management, sustainability, and climate change, these themes are then divided into multiple smaller-scale sub-themes. We find evidence, too, that most literature in the field of water resource management in developing contexts ironically came from developed countries, such as the United States (265), the United Kingdom (128), and China (98). There are several articles discussing water resource management in African countries or India. However, the number remained small. This study also relies on engineering publications, which suffer from its multidisciplinary perspectives.[2]

Acknowledgments

Further thanks to Nofie Iman Vidya Kemal, S.E., M.Sc., PhD., for suggestions in the discussion of water resource management in developing countries.

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Hoekstra, A. Y., & Hung, P. Q. (2005). Globalisation of water resources: international virtual water flows in relation to crop trade. *Global Environmental Change, 15(1)*, 45-56.

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Tiangui L., Wang, L., Xie, H., Zhang, X., & Zhang, Y. (2021). Evolutionary overview of water resource management (1990–2019) based on a

[1]This index is adjusted depending on the author's position in the list. The first author obtains most of the credit. Meanwhile, the second earns the second most. The remaining obtain the remaining credit as a proportion of their position.

[2]For instance, the economic, social, and political aspects of water resource management, especially in relation to China's expansive Belt Road Initiative (BRI) program, could be included in future studies.

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United Nations World Commission on Environment and Development. (1987). *Our Common Future*. The Brundtland Report.

Pimentel, D., Harman, R., Pacenza, M., Pecarsky, J., & Pimentel, M. (1994). Natural resources and an optimum human population. *Population and Environment, 15(5)*, 347-369.

Pimentel, D., Houser, J., Preiss, E., White, O., Fang, H., Mesnick, L., Barsky, T., Tariche, S., Schreck, J. & Alpert, S. (1997). Water resources: agriculture, the environment, and society. *BioScience, 47(2)*, 97-106.

doi: 10.14710/teknik.v43i3.46499

Appendix

Author rank based on H-index

No	Publication	Author	H-index
1	Naughton CC, 2018, Environ Sci Technol, 52, 11803	Mihelcic J.R.	2
2	Orner KD, 2017, Waterlines, 36, 167	Mihelcic J.R.	2
3	Abeysuriya K, 2007, Ecol Econ, 62, 174	Abeysuriya K.	1
4	Butterworth J, 2010, Water Altern, 3, 68	Batchelor C.	1
5	Moriarty P, 2010, Water Altern, 3, 122	Batchelor C.	1
6	Falk T, 2009, Water Altern, 2, 115	Bock B.	1
7	Butterworth J, 2010, Water Altern, 3, 68	Butterworth J.	1
8	Calzada J, 2017, J Environ Dev, 26, 400	Calzada J.	1
9	Hearne RR, 1997, Agric Econ, 15, 187	Easter K.W.	1
10	Easter KW, 1995, J Am Water Resour Assoc, 31, 9	Easter K.W.	1
11	Falk T, 2009, Water Altern, 2, 115	Falk T.	1
12	Falkenmark M, 2013, Int J Water Resour Dev, 29, 123	Falkenmark M.	1
13	Rockstrm J, 2007, Proc Natl Acad Sci U S A, 104, 6253	Falkenmark M.	1
14	Mihelcic JR, 2011, Chemosphere, 84, 832	Fry L.M.	1
15	Hanasaki N, 2013, Hydrol Earth Syst Sci, 17, 2393	Fujimori S.	1
16	Vairavamoorthy K, 2008, Phys Chem Earth, 33, 330	Gorantiwar S.D.	1
17	Hanasaki N, 2013, Hydrol Earth Syst Sci, 17, 2393	Hanasaki N.	1
18	Hearne RR, 1997, Agric Econ, 15, 187	Hearne R.R.	1
19	Hanasaki N, 2013, Hydrol Earth Syst Sci, 17, 2393	Hijioka Y.	1
20	Calzada J, 2017, J Environ Dev, 26, 400	Iranzo S.	1
21	Hanasaki N, 2013, Hydrol Earth Syst Sci, 17, 2393	Kainuma M.	1
22	Hanasaki N, 2013, Hydrol Earth Syst Sci, 17, 2393	Kanae S.	1
23	Hanasaki N, 2013, Hydrol Earth Syst Sci, 17, 2393	Kanamori Y.	1
24	Falk T, 2009, Water Altern, 2, 115	Kirk M.	1
25	Kyessi AG, 2005, Habitat Int, 29, 1	Kyessi A.G.	1
26	Hanasaki N, 2013, Hydrol Earth Syst Sci, 17, 2393	Masaki Y.	1
27	Hanasaki N, 2013, Hydrol Earth Syst Sci, 17, 2393	Masui T.	1
28	Abeysuriya K, 2007, Ecol Econ, 62, 174	Mitchell C.	1
29	Butterworth J, 2010, Water Altern, 3, 68	Moriarty P.	1
30	Moriarty P, 2010, Water Altern, 3, 122	Moriarty P.	1
31	Vairavamoorthy K, 2008, Phys Chem Earth, 33, 330	Pathirana A.	1
32	Mihelcic JR, 2006, Environ Eng Sci, 23, 426	Phillips L.D.	1
33	Calzada J, 2017, J Environ Dev, 26, 400	Sanz A.	1
34	Mihelcic JR, 2011, Chemosphere, 84, 832	Shaw R.	1
35	Butterworth J, 2010, Water Altern, 3, 68	Smits S.	1
36	Hanasaki N, 2013, Hydrol Earth Syst Sci, 17, 2393	Takahashi K.	1
37	Takahashi K, 2001, Int J Water Resour Dev, 17, 481	Takahashi K.	1
38	Mutikanga HE, 2009, J Am Water Works Assoc, 101, 57	Vairavamoorthy K.	1
39	Vairavamoorthy K, 2008, Phys Chem Earth, 33, 330	Vairavamoorthy K.	1
40	Butterworth J, 2010, Water Altern, 3, 68	Warner J.	1
41	Mihelcic JR, 2006, Environ Eng Sci, 23, 426	Watkins Jr. D.W.	1
42	Abeysuriya K, 2007, Ecol Econ, 62, 174	White S.	1
43	Falkenmark M, 1992, Popul Bull, 47, 1	Widstrand C.	1
44	Hanasaki N, 2013, Hydrol Earth Syst Sci, 17, 2393	Yamamoto T.	1
45	Hanasaki N, 2013, Hydrol Earth Syst Sci, 17, 2393	Yoshikawa S.	1

doi: 10.14710/teknik.v43i3.46499