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published in
Hydrology and Earth System Sciences
2009

DOI (link to publisher)
10.5194/hess-13-905-2009

document version
Publisher's PDF, also known as Version of record

Hydrol. Earth Syst. Sci., 13, 905–912, 2009
www.hydrol-earth-syst-sci.net/13/905/2009/

Hydrology and Earth System Sciences

HESS Opinions
"Urgent water challenges are not sufficiently researched"

P. van der Zaag[1,2], **J. Gupta**[1,3], **and L. P. Darvis**[1]

[1]UNESCO-IHE Institute for Water Education, Delft, The Netherlands
[2]Water Resources Section, Delft University of Technology, Delft, The Netherlands
[3]Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands

Received: 10 February 2009 – Published in Hydrol. Earth Syst. Sci. Discuss.: 2 March 2009
Revised: 5 June 2009 – Accepted: 5 June 2009 – Published: 23 June 2009

Abstract. In this opinion paper we submit that water experts conduct comparatively little research on the more urgent challenges facing the global community. Five specific biases are identified. First, research in the field of water and sanitation is heavily biased against sanitation. Second, research on food security is biased in favour of conventional irrigation and fails to address the problems and opportunities of rainfed agriculture. Third, insufficient water research is dedicated to developmental compared to environmental issues. Fourth, too little research is conducted on adaptation to climate change by developing countries. And finally, research on water governance has a fascination for conflict but too little eye for cooperation and meeting basic needs. This paper illustrates these biases with bibliometric indicators extracted from the ISI Web of Science. There is a stark mismatch between the global demand for knowledge and the supply of it. This mismatch is identified here as a problem that we water scientists must confront and resolve. We still lack a full understanding why this divergence between demand and supply occurs and persists; an understanding that is required to guide us towards aligning our research priorities to societal demands. The paper, however, makes some inferences. On the one hand, we should promote the global South to create its own research biases and allow it to develop alternative solutions. Simultaneously we would benefit from critical examination of our own research practice. Although this paper addresses a critical challenge it does not aim to be exhaustive or definitive. We merely identify the persistence of intransigent water problems as a valid research object in itself.

1 Introduction

What are the urgent water challenges that the world faces? There is certainly no lack of authoritative global assessments that articulate pertinent water challenges. Among these assessments are the UN Development Reports (UNDP, 2006; UNDP, 2007), reports related to the Millennium Development Goals (e.g. UN, 2005; UN Millennium Project, 2005), the Biennial Report on Freshwater Resources (Gleick, 2008), and the tri-annual World Water Development Reports (UNESCO, 2006). Other important documents are regularly produced by the FAO on food and food insecurity (FAO, 2008a, b), by the Intergovernmental Panel on Climate Change on, inter alia, climate change and water (Bates et al., 2008), and by the World Resources Institute (WRI, 2008). The Millennium Ecosystem Assessment (2005) and the Comprehensive Assessment of Water Management for Agriculture (Molden, 2007) also discussed key water issues.

These reports continuously formulate and re-formulate challenges that are all variations and specifications of a limited set of problems, many of which having a significant water dimension. The most important of these water problems may be summarised as follows:

1. *Sanitation:* Whereas access to potable water for all remains a formidable challenge, an even greater challenge is to ensure adequate sanitation for all. Forty percent of humanity remains without access to adequate sanitation services, and this percentage is proving difficult to bring down. Sanitation directly influences human health and productivity, especially in densely populated areas. Moreover, lack of proper sanitation is frequently associated with environmental degradation.

2. *Food security:* Many households remain food insecure. Crop yields have to increase, also in order to feed an ever-growing population. Many smallholder farmers, especially in Sub-Saharan Africa, do not manage to

Correspondence to: P. van der Zaag
(p.vanderzaag@unesco-ihe.org)

achieve grain yields above 1.5 tons per hectare. Due to variability of rainfall, harvests regularly fail directly affecting livelihoods. Soil nutrients and water are limiting factors that can, however, be overcome (Falkenmark and Rockström, 2004).

3. *Freshwater ecosystem integrity:* Economic development is accompanied by environmental externalities. Resource use leads to over-abstraction of water from rivers and aquifers, to pollution of air, water and soil, and has completely modified hydrological regimes. This negatively affects the integrity of ecosystems, which is not only detrimental to plant and animal life, but also to human beings, as humans rely on ecosystem services for their livelihoods and recreation.

4. *Adaptation to climate change:* There is an urgent need to enhance the capacity of water systems to respond to the potential impacts of climate change, such as increased variability of rainfall, increased intensity and frequency of extreme events, and, in many parts, a decrease in the utilisable amounts of surface- and groundwater.

5. *Governance:* Where there are problems of water scarcity, sanitation, food security, water pollution or extreme events, tensions arise between rival water users (and rival water uses) and between rival uses of scarce government resources. These problems occur at different levels of governance, in rural and urban areas, involving individual actors, communities, and nation states. Developing legitimate institutions that adequately deal with such dilemmas and potentially conflictive situations is a major scientific and political challenge. Given the global trends of change, such situations are likely to occur more frequently and in more intense forms in future requiring more responsive governance systems.

Are water scientists contributing sufficiently to resolving the above challenges? The answer is straightforward: they don't. Our experience as water researchers and teachers has led us to hypothesise that there are serious mismatches between water problems and the water research devoted to these problems. We decided to test this intuitive and experiential hypothesis through a quick assessment of bibliometric data on the research output in the field of water. Our analysis is based on data from ISI Web of Knowledge (http://isiwebofknowledge.com) and the methodology followed is described in the Appendix. This analysis confirmed our hypothesis.

Table 1. Scientific papers on water supply and drinking water versus sanitation, 1998–2007.

search term in title, keywords and abstract	Papers
water AND drinking NOT sanitation	20 371
water AND sanitation NOT drinking	792
water AND drinking AND sanitation	178
	21 341

Source: http://isiwebofknowledge.com

2 Research in the field of water is heavily biased against sanitation

Research in the field of water is heavily biased against sanitation and this may explain why so little progress is made on this issue (Table 1). This is of great concern given the current sanitation crisis. The sanitation crisis is a three dimensional problem: it severely compromises human health; it creates severe pollution loads and thus impacts the environment negatively; and it represents a waste of rapidly depleting nutrients that could be a resource for food and/or energy production. Of the small research output on sanitation, most is produced in the developed countries, and few research subjects are initiated, carried out and/or published by knowledge institutions in the global South (Table 2). This is hardly surprising: in countries where sanitation needs are the largest, the number of research and development experts is lowest, and hence the capacity to develop homegrown solutions is constrained (Gupta and Van der Zaag, 2009). This is a relevant observation since sanitation practices are influenced by locally specific biogeochemical, socio-economic, cultural and institutional aspects. Yet, compared to bibliometric statistics on some other water topics (see next sections), the contribution on sanitation research by developing countries is not negligible (above 10%). Some may argue that the lack of articles on sanitation may reveal that this is seen as a social and political challenge rather than a scientific challenge. We beg to differ. The social, economic and political aspects of this issue should be seen as a social science challenge, with a concomitant academic output in the form of research papers in social science journals.

3 Research on food security is biased in favour of conventional irrigation, and fails to address the problems and opportunities of rainfed agriculture

Furthermore, there are five times more research papers on irrigation that do not take rainfed agriculture into account than there are papers that address both issues or that only address rainfed agriculture (Table 3). This is remarkable considering that so many more people depend on rainfed agriculture for

Table 2. Location of the institution of authors of scientific papers on sanitation, 1998–2007.

water AND sanitation NOT drinking		water AND sanitation AND drinking	
developed countries	77.5 %	developed countries	69.3 %
countries in transition	13.1 %	countries in transition	13.4 %
developing countries	9.4 %	developing countries	17.3 %

Source: http://isiwebofknowledge.com

Table 3. Scientific papers on rainfed and irrigated agriculture, 1998–2007.

search term in title, keywords and abstract	papers	citations	citation average
water AND "irrigated agriculture" NOT "rainfed agriculture"	333	1858	5.6
water AND "rainfed agriculture" NOT "irrigated agriculture"	62	426	6.9
water AND "irrigated agriculture" AND "rainfed agriculture"	8	35	4.4
	403	2319	5.8

Source: http://isiwebofknowledge.com

Table 4. Location of the institution of authors of scientific papers on rainfed and irrigated agriculture, 1998–2007.

water AND "irrigated agriculture" NOT "rainfed agriculture"		water AND "rainfed agriculture" NOT "irrigated agriculture"	
developed countries	73.3%	developed countries	55.3%
countries in transition	16.8%	countries in transition	27.6%
developing countries	9.9%	developing countries	17.1%

Source: http://isiwebofknowledge.com

their livelihood than on irrigation, and despite the social, economic and health problems associated with low crop yields of rainfed agriculture in many semi-arid tropical and subtropical regions. It is interesting to note that the share of developing countries and countries in transition contributing papers on rainfed agriculture is large (44.7%, see Table 4).

4 Insufficient water research is dedicated to developmental compared to environmental issues.

Poor sanitation and food insecurity are both associated with poverty, but there are no simple cause – effect relations: Are people poor because they lack access to adequate sanitary services or is it the other way around? Low crop yields certainly contribute to the vulnerability of rural livelihoods, but are higher and more secure crop yields a sufficient condition for rural people to extricate themselves out of poverty? In order to answer these questions, the complex dynamics that exist between poverty, livelihoods, infrastructure, institutions, and access to natural resources and essential services must be considered. Socio-economic development is both a result of *and* a prerequisite for resolving the sanitation and agricultural challenges. Eradicating poverty is therefore the central Millennium Development Goal. Without broad-based economic development most of the other development goals, as well as the water, sanitation, maternal health and food security targets, are not achievable.

There will be environmental consequences, both positive and negative, associated with such broad-based socio-economic development. These ecological concerns obviously merit attention, but given the urgency of the water problems identified, it is expected that the research output on developmental (economic) issues in a water context would be of the same order, or larger, than that on environmental (ecological) issues.

To verify this hypothesis we compared the number of research papers on water and economic development with those on water and the environment. According to the ISI Web of Knowledge database, three times more papers deal with the latter and these are cited much more frequently (Table 5). Remarkably, less than 1% of all papers mention both issues. Scientists from developing countries contribute a negligible number of papers concerning water and environmental issues but author significantly more research papers dealing with water and economic development (Table 6).

Table 5. Scientific papers on ecology and environment and on development and economy, 1998–2007.

search term in topic title, keywords and abstract	papers	citations	citation average
water AND ecology AND environment NOT (development AND economy)	869	11 395	13.1
water AND development AND economy NOT (ecology AND environment)	288	2048	7.1
water AND development AND economy AND (ecology AND environment)	8	52	6.5
	1165	13 495	11.6

Source: http://isiwebofknowledge.com

Table 6. Location of the institution of authors of scientific papers on ecology and environment, and on development and economy, 1998–2007.

water AND ecology AND environment NOT (development AND economy)		water AND development AND economy NOT (ecology AND environment)	
developed countries	83.2%	developed countries	66.2%
countries in transition	15.3%	countries in transition	26.7%
developing countries	1.5%	developing countries	7.1%

Source: http://isiwebofknowledge.com

Table 7. Scientific papers on climate change, adaptation and mitigation, 1998–2007.

Search terms in title, keywords and abstract	papers	citations	citation average
climate change AND adaptation NOT mitigation	837	10 666	12.7
climate change AND mitigation NOT adaptation	565	5694	10.1
climate change AND mitigation AND adaptation	118	1192	10.1
	1520	17 552	11.5

Source: http://isiwebofknowledge.com

Table 8. Location of the institution of authors of scientific papers on climate change, adaptation and mitigation, 1998–2007.

climate change AND adaptation NOT mitigation		climate change AND mitigation NOT adaptation	
developed countries	90.0%	developed countries	85.3%
countries in transition	8.6%	countries in transition	13.0%
developing countries	1.4%	developing countries	1.6%

Source: http://isiwebofknowledge.com

5 Too little research is conducted on adaptation to climate change by developing countries

It is widely acknowledged that climate change will hit developing countries hardest. The impacts on the sub-tropical and tropical areas are expected to be more severe than in the temperate zones. These impacts come over and above the existing challenges that these countries already face in the form of huge variabilities, shocks and uncertainties in hydrology (naturally occurring floods and droughts), economy (fluctuations in world market prices, for example) and in political terms, compromising their capacity to meet the basic needs of their populations. These countries and their citizens are constantly busy with adapting to changing circumstances, be these natural or man-made. They cannot afford to spend scarce resources to systematically investigate the origin and future trends in these variabilities. This is reflected in the bibliometric data: developing countries contribute a negligible amount of papers on adaptation to and mitigation of climate change. The countries that are primarily responsible for climate change themselves dominate the scientific output, both on mitigation and adaptation strategies for climate change (Tables 7 and 8).

Table 9. Location of the institution of authors of scientific papers on water and biofuel, 1998–2007 (n=165).

water AND biofuel	
developed countries	86.6%
countries in transition	13.4%
developing countries	0.0%

Source: http://isiwebofknowledge.com

The climate change challenge that developing countries face is exacerbated by the recent and sudden increase in biofuel demand as a result of the EU and USA seeking to mitigate their greenhouse gas emissions and to reduce their dependency on oil exporting countries. As biofuel production competes with existing uses of land and water resources, the North partly externalises its biofuel demands to the South. But also in the South, biofuel production competes with existing land and water uses. This leads to policy dilemmas in many developing countries: between export-led development versus livelihood security scenarios. Yet these countries have limited research capacity to critically analyse these dilemmas and propose appropriate policies. This is illustrated by Table 9: During 1998–2007 only 165 scientific papers dealt with "water" and "biofuel", none of which was authored by institutions located in developing countries. The huge land and water concessions that European and American investors, fuelled by lucrative subsidy schemes, are currently acquiring in countries such as Ethiopia, Mozambique, Peru and Tanzania for establishing large biofuel plantations pinpoint at weakly developed and/or weakly respected resource rights of local communities, especially concerning access to land (Keyzer et al., 2008) and water (our own observations). The water dimension, however, receives too little attention (Uhlenbrook, 2007).

6 Research on water governance has a fascination for conflict but too little eye for cooperation

Tensions arise where problems of water scarcity, sanitation, food security, water pollution or extreme events occur. What type of research is required to prepare ourselves to deal with increasingly fierce competition over water between rival water users that seems inevitable in the near future? Table 10 shows that there is a clear fascination in the literature for water conflict, as there are many more research papers that mention water conflict in their title than there are papers on water cooperation. Table 11 shows that this skewedness is even more extreme in the research output of developing countries. Conflict rightfully attracts attention and requires to be understood before it can be resolved. But the fact that there is more talk and thought about water conflict than about water cooperation may have a self-fulfilling effect. Is this focus on conflict sufficient to better understand how to share water peacefully? It is in our view urgent to better understand why water is often a factor of collaboration between communities, nations and people. This insight can help us build stronger and robust water sharing arrangements between user groups that all have legitimate claims to scarce water. Merrey (2009) demonstrates that there is a paucity of knowledge on African models of cooperation, and there is even less research on the possibilities of upscaling local level collaborative arrangements, for example to improve the effectiveness of river basin organisations.

7 Bibliometric analysis is one indicator of research imbalances

While the above bibliometric analysis confirmed our intuitive hypotheses – the analysis is clearly limited. We identify five limitations. First, our bibliometric analysis is small in scope. It excludes scientific publications outside the published international peer-reviewed English language journals. It excludes English language scientific journals that are not included in the ISI Web of Knowledge and it omits the extensive body of grey literature.

Second, there are obvious weaknesses with respect to the search terms used in some of the queries. However the trends in most of the queries are so clear that the emerging picture is undeniable. More in-depth research is clearly needed, but is beyond the scope of this opinion article.

Third, a vexing question related to using citation indices is whether this is a measure that is sound for the purpose of measuring societal (rather than scientific) impact. It most probably is not. The number of citations in international peer reviewed journals does not measure how often that research has been applied in practice and has made a (local) impact in the real world. To measure that impact we need indicators that supplement the citation scores. A slightly better indicator than the number of citations might be the number of people that have read a paper. With electronic (web-based) subscriptions it is possible to count the number of downloads which may be an easy (but admittedly rough) proxy for the number of times a paper has been read.

Fourth, it may be argued that some of the research that needs to be done urgently in the water area would not be sufficiently innovative to be acceptable for certain high-ranking scientific journals. This might mean that less research resources are available for the purpose of such kinds of research. National Science Foundations may find research into the social challenges of sanitation less innovative than developments in bio technology, for example. Furthermore, high quality researchers may also be drawn more to innovative niche areas rather than common day-to-day problems. Furthermore, researchers may find it difficult to develop conceptually and/or empirically sound scientific papers in these issue areas. This calls for redesigning funding systems,

Table 10. Scientific papers on water conflict and water cooperation, 1998–2007.

term in title	papers	citations	citation average
water AND conflict NOT cooperation	91	317	3.5
water AND cooperation NOT conflict	30	96	3.2
water AND cooperation AND conflict	11	28	2.5
	132	441	3.3

Source: http://isiwebofknowledge.com

Table 11. Location of the institution of authors of scientific papers on climate change, adaptation and mitigation, 1998–2007.

water AND conflict NOT cooperation		water AND cooperation NOT conflict	
developed countries	85%	developed countries	76%
countries in transition	8%	countries in transition	24%
developing countries	7%	developing countries	0%

Source: http://isiwebofknowledge.com

research and publication criteria to ensure that relevant research is also encouraged upstream by funding agencies as well as downstream by journals.

Finally, there is the problem of lack of sufficiently long time series of biophysical data in many tropical areas, that may result in research papers being rejected by journals. This dilemma has been well identified by Buytaert (2009), who noted that "New techniques are difficult to apply and evaluate in data scarce areas." Let us accept the lack of water data as a reality, and explore what this implies for the research practice. What does this mean for the methodologies we adopt? What can we learn from research programmes such as PUB (prediction in ungauged basins)? How can professionals and decision-makers benefit from some of the new observation technologies? What does uncertainty imply for the scientific method? Winsemius (2009) starts to give some interesting answers.

8 Conclusions

This opinion paper has argued, first, that research in the field of water and sanitation is heavily biased against sanitation. Second, that research on food security is biased in favour of conventional irrigation, and fails to address the problems and opportunities of rainfed agriculture. Third, insufficient water research is dedicated to developmental compared to environmental issues. Fourth, too little research is conducted on adaptation to climate change by developing countries. And finally, research on water governance has a fascination for conflict but too little eye for cooperation and meeting basic needs.

The pertinent global water related problems thus remain under-researched. The lack of knowledge on these problems is clearly sub-optimal and very costly in human, social, economic and political terms.

Furthermore, the innovation potential of inter-disciplinary research remains underutilized. Overcoming the disciplinary biases that we all have (if there is a water problem water engineers tend to prescribe pipes, water lawyers rights, and water economists correct prices) may open up new possibilities. Progress is likely when disciplines are crossed and combined. Interdisciplinary and integrated approaches are, however, not obvious, especially since many epistemic and institutional obstacles need to be overcome. One clear example is that at this moment there are no leading academic journals that can rightfully claim to adequately cover the (admittedly ill-defined) inter-disciplinary field of integrated water resources management.[1]

The imbalance in research confirms that science mirrors the socio-economic global divide (Annan, 2003; UNESCO, 2005) and reflects the geographical imbalance of research

[1]The impact factor of *Water Resources Management* is relatively low (IF= 0.79). *Water Policy* has only recently been admitted as an ISI journal, and no impact factor is available. The *International Journal of Water Resources Development* recently lost its ISI recognition. The new journal *Water Alternatives* has just been inaugurated and therefore does not yet have ISI recognition. The *Journal of River Basin Management* is a relatively new journal seeking ISI recognition. *Water International* has an IF of only 0.37. There are two journals with a considerable academic reputation on water management, namely *Journal of Water Resources Planning and Management-ASCE* (IF=1.03) and *Journal of the American Water Resources Association* (IF=1.436), but both journals do not claim to represent the full breath of the IWRM field.

capacity and research funding. Karlsson et al. (2007) confirmed the existence of the global knowledge divide when they found that the developed countries, representing 20% of the world population, publish nearly 95% of all papers in the nine top environmental science journals. The problem is exacerbated because there is a systematic difference in climatic conditions, and thus in water related issues, between developed and developing countries. It is therefore no surprise that whereas the temperate zone accounts for 25% of the world land mass, 83% of the scientific papers in the journals sampled by Karlsson et al. (2007, p. 678) were based on work done there. This thus creates a wealth of knowledge on relevant processes in temperate zones, and a dearth of knowledge on processes that are relevant elsewhere.

If this is true, then one obvious way to contribute to a more balanced research agenda is to prioritise the strengthening of research capacity in the global South. There are encouraging signs that the share in scientific output of Latin American countries as well as the newly industrialised countries in Asia is rapidly increasing. But research output in other regions remains stagnant, notably Sub-Saharan Africa, the Arab States, Central and Eastern Europe and parts of Asia (UNESCO, 2005). It is precisely in these regions where major water challenges remain unresolved. It is here where research partnerships with other water scientists from the South (South-South cooperation) and with colleagues from the global North (South-North cooperation) could make a difference.

There are several regional examples of successful South-South-North academic partnerships that are starting to make significant contributions to pertinent water issues. Among these are *Concertación* in the Andean countries in Latin America (Rap, 2008), *Crossing Boundaries* in South Asia (Gunawardena, 2008), and *WaterNet* in Southern Africa (Nyabeze, 2007). Scientific evidence of such successes is, however, not sufficiently documented (but see Van der Zaag, 2007).

Elsewhere we have argued that the South should be allowed and enabled to create its own research biases (Gupta and Van der Zaag, 2009). This would enhance the diversity in research experiments and hence the chances of developing innovative and alternative solutions. One practical way of promoting research capacity is through establishing "regional water research funds". Such regional research funds are well placed to promote research capacity and create institutional spaces where regional research agendas are defined, implemented, reviewed and refined (Van der Zaag, 2009).

To begin to address the observed weaknesses in our scientific practice, water scientists must start to acknowledge the biases in our own research work, and try to understand the mechanisms that influence it. We need to realise, first, that the pressure to achieve academic success will influence the choice of research topics: domestic water supply and irrigation may then be chosen at the expense of sanitation and rainfed agriculture, for example. Paradigms do influence what are considered good and challenging research topics that more easily lead to academic success. Second, the agendas of research funds to which we researchers respond are often not set by the envisaged users of the research findings, but rather by peer researchers. Here the agenda setting may lack sufficient signals from the real world. Third, as we researchers are often rewarded on the basis of achieving high bibliometric impact (citations of my research work) this may divert our attention for societal impact (has my research work improved the professional practice, e.g. through making an effort to publish also in local non-ISI journals, in non-English language journals, and in professional magazines).

The necessity of raising the awareness regarding our research ethos is not only imperative but will also be beneficial to us researchers as well as the users of our research findings. We are convinced that a bit more self-examination would contribute to a more balanced research agenda that genuinely addresses the great water challenges, including improved sanitation, increasing crop yields in rainfed agriculture, restored ecosystem health and the creation of more robust and adequately governed water systems. We further argue that the persistence of intransigent water problems, and how it can be resolved, is a valid research object in itself.

Appendix A

A methodological note

The dataset used in this paper originates from the Thomson Reuters Web of Science http://scientific.thomson.com/products/wos/ which provides access to multidisciplinary information from over 8700 journals worldwide. The queries were performed in all the three available databases of the ISI Web of Science, i.e. Science Expanded, Social Science, and Arts & Humanities. The method of inquiry used to extract the data was established by using specific syntax which was considered relevant in the context of this discussion paper and covered the time span 1998–2007. As a consequence, the ISI data presented in this discussion paper is dependent on the keywords utilized in the queries. In Tables 1 through 9 the queries were performed by searching in title, keywords and abstract. The query in Tables 10 and 11 was conducted in the title field only.

The classification of countries as developed is based on the OECD list for developed countries. The criterion of GDP per capita per year expressed in "purchasing power parity" (PPP, as published in the 2006 UNDP Human Development report; UNDP, 2006) was used to differentiate developing countries from countries in transition. Countries with an annual per capita income lower than US$ (PPP) 7500 were considered developing countries. All other countries were considered countries in transition (including countries such as Argentina, Brazil, China, Egypt, India, Israel, Malaysia, Saudi Arabia, Slovenia, South Africa and Taiwan).

Acknowledgements. We acknowledge the valuable and stimulating comments and suggestions by the following four referees: Erik Mostert, Larry Swatuk, François Molle and Murugesu Sivapalan. An earlier version of this paper, based on data derived from a different source (Scopus), was presented at the European Geophysical Union General Assembly in Vienna, 18 April 2008. Joyeeta Gupta wishes to acknowledge that her contribution to this paper was undertaken in the context of the "Inter-governmental and private environmental regimes and compatibility with good governance, rule of law and sustainable development" project, which is financially supported by NWO, the Netherlands Organisation for Scientific Research (Contract: 452-02-031).

Edited by: H. H. G. Savenije

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