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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Global scale human pressure evolution imprints on sustainability of river systems" *by* Serena Ceola et al.

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The authors gratefully acknowledge Wouter Berghuijs for his positive and extremely detailed review. In what follows in *italics* are the comments provided by the Referee, and in **bold** fonts the authors' response, inclusive of the indication on how the text will be modified within the next days to comply with the Referee' recommendations and comments.

This paper presents an interesting and novel analysis of how human pressures on river systems have evolved over the period 1992-2013 for over 2000 rivers globally. The paper introduces the metric "Differential Human Pressure on Rivers" to quantify human pressures on rivers. The paper defines Human pressure on rivers as the ratio between

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the cumulative human presence and activity across the contributing area (here: sum of nightlights) and the natural discharge generated within the same contributing area. Applying this metric to river flow and nightlight data indicates that, on average, human pressure has slightly increased on river systems (+1.6% per year over the 1992-2013 period). These results also indicate hotspots of change (e.g. northern tropical and equatorial areas). The paper states this offers guidance on where the development and implementation of mitigation strategies and plans are most needed. This paper addresses a relevant topic and therefore is potentially very suitable for publication in HESS. The results that are presented are interesting. Overall the paper is relatively clearly written and I enjoyed reading it.

The authors wish to thank Wouter Berghuijs for his recognition of our research idea and his overall appreciation of the manuscript.

However, before I can recommend publication of this work, several things need to be clarified. Please see our detailed replies below.

The revised manuscript including the suggested changes, if accepted, will be uploaded in the next few days.

****Why normalize by river discharge?*** It seems that changes in pressure on river systems (DHPR) are mathematically independent of a location's discharge (since DHPR looks at relative changes and runoff is assumed constant per location). Thus, the "Differential Human Pressure on Rivers" solely quantifies changes in nightlight data along a river network. This is not wrong, but this does not match the description that is used throughout the paper.*

We normalized by river discharge to distribute human presence and activity on natural available discharge, following the approach developed by Vörösmarty et al. (2010). DHPR is based on the analysis of the temporal evolution of standardized human pressure on rivers F_i(t), as defined by Eq. (10) in the original manuscript. Standardized human pressures, and thus DHPR, are a function of

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the (i) ratio between human presence and activity, HP_i, and discharge, Q_i, and (ii) its minimum and maximum values, which consider both HP and Q. As a consequence, DHPR is not totally independent of Q. Our approach, as defined in this manuscript, considers stationary discharge. However, it is planned in the near future to consider time varying natural flows, to explicitly embed variations in both drivers. As an example, we performed a preliminary study on a few catchments across China and Myanmar, using discharge data provided by GRDC (Global Runoff Data Centre). Standardized human pressures on rivers are reported in Fig. R1, where a comparison between time varying and constant discharge is shown.

****To what extent is nightlight data representative for human pressure on rivers?*** I understand that nightlight data is actually a useful proxy for "human presence and activity" but whether it is a good proxy for human pressure ON RIVER SYSTEMS is never shown. Sure, we expect that places with no nightlight tend to have very little human pressures on the river system, and that places with a lot of nightlight data, potentially have a great influence on river systems. However, many aspects that most greatly pressure river systems (e.g. irrigation, dams, etc.) are probably not necessarily very correlated with nighttime data?. I do not say this because I think nighttime data is not useful, I just think it would be very helpful to make clearer/discuss to what extent nighttime data represents actual pressures ON THE RIVER SYSTEMS.*

In our manuscript we state that the ratio between nightlight and river discharge can be considered a useful proxy for human pressure on river systems. The reason to assume this stems from the statistically significant correlation with existing and well acknowledged datasets, such as water threats (Vörösmarty et al., 2010) and human footprint (Sanderson et al., 2002; Venter et al., 2016), which propose complex and data-demanding metrics to measure human pressure on natural systems. Our approach, although relatively simple, defines human pressure on rivers as a basin scale cumulative effect of residing population and its

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economic activities on the natural river discharge at the basin outlet. In other words, we focus on (1) how many people live and act on a river basin (namely, the sum of nightlights) and (2) in which way this anthropogenic effect is diluted with river discharge. Local aspects such as dams and water withdrawals for civil, industrial and irrigation purposes are not taken into account. Therefore, nightlights and river discharge are considered the sole controlling and the best representative drivers of human pressure on rivers. Our analysis allows to quickly assess human pressure on rivers, with several potentialities for the identification of hot spot areas of change in pressure. This part will be added in the revised manuscript.

****To what extent are changes in time in nightlight data representative for changes in time?*** The validation of DHPR is done on a spatial comparison with previously used metrics. What makes you confident that the metric can meaningfully quantify changes in time in human pressure (rather than characterize differences in space)?*

Thanks for this remark. This is a quite challenging task (also linked to your previous question), since to our knowledge there is no availability of alternative metrics that show changes in time of human pressure on rivers. One could use, as also reported in the manuscript, population gridded data (e.g. Gridded Population of the World, or Global Human Settlement Layer), as an alternative proxy of human presence and activity. However, these datasets present several limitations (exponential growth model, uniform densities across a municipality), which do not allow for a robust validation in time. If you are aware of any additional dataset which shows changes in time of human pressure on rivers, we will be happy to elaborate more on this.

****What makes a hotspot a hotspot*** Hotspots can be identified based on absolute pressure, or changes in pressure. The focus in this paper seems on the latter. However, these are all "relative changes" in pressure, but is a relative change really relevant when the "absolute pressure" is very low"?*

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Thanks for this comment. To better explain this issue and reply to your question, we show in Fig. R2 a comparison among (a) the relative change in pressure, DHPR, (b) the long term average standardized human pressure on river systems $\overline{F}$, where the value at the outlet is uniformly distributed across each river basin, and (c) the absolute change in pressure, as the product between DHPR and $\overline{F}$. Marked absolute changes in pressure are evident only for river basins with relatively high standardized human pressures. These absolute changes, expressed as % per year, are evidently proportional to absolute pressures and thus it is not possible to compare trends across basins. We used normalized values of human pressure in order to compare trends at global scale, independently from absolute human pressure values, which are influenced by catchment size, human presence and activity (namely, the sum of nightlights) and discharge.

****To what extent do the results say anything about human security and sustainable development*** Result are often put in these big terms. For example "Our study identifies critical zones where the change rate of human pressure will undermine human security and sustainable development in the near future." This statement seems unfounded and a strong overinterpretation of the results. Undermine human security? Sure, this may be related to your index, but that cannot be seen from any of the results that you have (any linkage there is purely speculative and not scientifically shown by your work). I would suggest to tone down the interpretation a bit, and more focus on the facts that you actually show*

Thanks for this remark. This statement, as also reported below as a reply to one of your questions, will be toned down.

****Detailed comments below*** Note that, at times, "buzzwords" with an unclear/unspecific meaning are used which makes it for me difficult to follow at times) I made some suggestions in the detailed comments below, but this is not necessarily exhaustive. I would encourage using clearly defined terms throughout the paper. I think all these issues can be addressed with textual changes, and I look forward to seeing a*

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final version being published soon in HESS.

Thanks again for your positive comments. We will modify the text, accordingly to your suggestions.

Detailed comments Throughout the entire paper: "Vorosmarty" should be "Vörösmarty".

Ok.

Page 1 L2: The part "with severe implications for anthropogenic activities and river ecosystems" seems redundant and makes the sentence slightly awkward to read.

Ok, this part will be removed.

L3: "was already exposed" instead of "was exposed [. . .] already".

Ok, thanks.

L4: can you be more specific than "these threats (to water security)"? If no, that's ok. If yes, that would be helpful. That water security is becoming an increasingly relevant topic is namely not new. Quantifying its changes is.

We agree that introducing water security in the abstract of the manuscript without a precise contextualization may be distracting. For this reason, in the revised manuscript we will remove the term "water security" and use "human pressure". The sentences will read: "Previous studies showed that a large part of global river systems was already exposed to relevant anthropogenic pressures at the beginning of this century. A relevant question, which was never explored by the literature so far, is whether these pressures are increasing in time, therefore representing a potential future challenge to the sustainability of river systems."

L5: I would suggest to remove "simple, objective and effective". All these qualifications are arbitrary, and I would let the reader decide to what extent this is the case.

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Agreed.

L6: "to quantify" instead of "to measure".

Ok.

L7: normalized human pressures "on river systems" (considering adding the last past for clarity).

Ok, thanks.

L8: "time invariant discharge data" sounds odd. The data itself is not time invariant, which this wording suggests (to me). Maybe use "time-averaged" which is nearly the same but seems to be a better fit (to me).

Instead of using "time invariant" we will use "stationary".

L9-11: This sentence reads a bit odd. Consider "The results show that normalized annual human pressure on river systems increased globally, as indicated by an average DHPR value of 1.9% per year, whereby the greatest increases occurred in the northern tropical and equatorial areas."

Perfect, thanks for the suggestion.

L10: It seems to me the units of change (DHPR) are % per year, not %?

Right. We will modify units of measurement for DHPR along the entire manuscript.

L12: "the development and implementation of mitigation strategies and plans" is very unclear to me. I guess that's ok, but if you can be more precise that would be helpful.

We prefer to keep this sentence as is. Our approach can quickly identify hot spot areas of change and thus help towards the definition of possible strategies aimed at controlling the evolution in time.

L15: Consider something like "have been extensively reported" instead of "than have

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been well established". OK, maybe my suggestion is not great either, but "established" seems to be an odd verb to use here.

Your suggestion sounds reasonable and better that our original version. The text will be modified accordingly.

L16: "Increasing" instead of "Enhancing".

Ok.

L21-22: Consider "how human pressure on river systems can be sustainable in the long term" instead of "if human pressure on river systems is going to be sustainable in the long term."

Fine.

Page 2 L2: Consider "be assessed" instead of "be then inspected"

Ok.

L3-4: "in sensitive areas" seems to be redundant/or unnecessarily specific?

Ok, this part will be removed.

L13: "this analysis" or "such analyses"?

We prefer to keep the sentence as is.

L14: "allow" or "provide"?

We accept your suggestion and in the revised manuscript we will use "provide".

L14-15: "for the analysis and identification of the main drivers of human pressure on river systems" or "to analyze and identify human pressures on river systems"

This sentence in the revised manuscript will read: "Powerful tools are now available to carry out this analysis. Earth system modeling and remote sensing observations have produced global datasets that provide unprecedented possibil-

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ities to analyze and identify human pressures on river systems, as well as their progress in time."

L19: Consider being explicit that you propose "A simple and effective methodology" (rather than "is proposed" which makes it unclear who has done this).

Thanks for this. In the revised manuscript the sentence will read "We propose. . ."."

L23-24: "which epitomize surface hydrological processes within a river basin and represent the river natural flow regime" seems redundant (first part) and not necessarily accurate (second part), so I would suggest to remove it.

We partly accept your suggestion and here it is our revised sentence "Natural discharge values, which epitomize surface hydrological processes within a river basin, are computed from runoff data.".

Page 3 L6: "concluding" instead of "conclusive".

Ok.

L9-11: "The Simulated Topological Network STN-30 (Vorosmarty et al., 2000a, b; Fekete et al., 2001) was the digital river network used in this work."

This comment is not clear. Could you please provide us a feedback?

Page 4 L3: "which overcomes" instead of "which overcome"

Ok.

L25-28: "The computational steps explicitly incorporate catchment topology and use a routing scheme based on flow directions to evaluate the downstream accumulation of human presence and activity and natural river discharge" It seems that in the end the method does not incorporate river discharge?

The method evaluates the downstream accumulation of human presence and

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activity and river runoff, defined as the sum of nightlights and natural river discharge, respectively. In the revised manuscript, we will use "runoff" instead of "discharge".

Page 5 L13: Can you explain why "Standardization was essential to test the reliability of the proposed methodology."?

This sentence is connected to the following one. An "indeed" will be added to better clarify this point.

L22: "clearly" seems redundant (and arbitrary).

Ok.

L24: the unit is % per year? not %?

Yes, thanks.

Page 6 Line 24: "Student's T-test" or "Student's t-test"?

We will use "Student's *t*-test" throughout the whole manuscript.

Section 2.4: Can you comment on why a significant correlation in SPACE between this variable and previous metrics warrants the use of DPHR (which quantifies changes in TIME)?

As also stated above, to support the reliability of our metric of human pressure on rivers, we compared it against existing methodologies. The goal was to prove that our method provides results similar to previous metrics, but, differently from them, it allows the analysis over time. Thus, given the statistically significant correlation among the considered variables, our metric of human pressure on rivers can be used as a reliable variable and then changes in time can be quantified. We will change the text as follows: "We computed P-values from the Student's t-test and the coefficient of determination R^2 to check the statistical significance of the regression analysis. A statistically significant correlation in

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space between our estimates of human pressure on rivers and previous metrics warrants the use of the proposed variable as a valuable alternative. In addition, given the availability of time series, it allows the quantification of changes in time.".

Page 7 L5: what do you mean by "and then consolidated by region", do you mean "grouped by region"?

Yes, the manuscript will be changed accordingly.

L9: "extent", not "extension"?

Ok.

L33: I do not know why does would "clearly imply severe endangerment levels" (beyond a reader's own interpretation)? what does "severe endangerment levels" actually mean here?

High human pressure values well correlate with high water threats and human footprints, which identify high risk conditions (i.e. severe endangerment levels). If needed, we can change this sentence in the manuscript.

Page 8 L2: "human footprint focuses on the entire terrestrial realm and does not explicitly consider river systems" can you be more precise/specific here? I do not know what this means.

Thanks for this remark. We realized that this sentence was not totally accurate and we propose to modify it as follows: "A better correlation was found with water threats, rather than human footprint values. This was expected, since human footprint considers the entire terrestrial realm and does not exclusively focus on river systems.".

L6: what do you mean by "recent outcomes on the terrestrial realm"?

"Terrestrial realm" will change in "terrestrial environment".

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L7: Be explicit that you now talk about hot spot regions OF CHANGE.

Ok, thanks.

L8-9: "at an accelerated pace" seems redundant (and is something that is not looked at in this paper), therefore I suggest to delete it.

Agreed.

L11: units are % per year?

Yes, thank you.

L32-33: "DHPR identifies critical zones where increasing trends in human pressure on river systems will undermine human security and sustainable development in the near future." This seems like a strong overstatement to me (i.e. how do we know these areas will "undermine human security and sustainable development in the near future"?). I would really recommend toning down this statement.

Ok, thanks. We will modify the sentence as follows: "DHPR identifies critical zones where increasing trends in human pressure on river systems may undermine human security and sustainable development in the near future.".

L33-34: "River basins located within the northern subtropical and equatorial belts across Africa and Asia clearly epitomize this situation, showing markedly positive change rates in the 1992 to 2013 period". Making a statement on strong positive DHPRs in these regions is fine. I believe you cannot say (from your results) that these numbers simply show "critical zones where increasing trends in human pressure on river systems will undermine human security and sustainable development in the near future".

According to your comment, we toned down and slightly rearranged our sentence, which now reads: "Hot spot areas of change are represented by river basins located within the northern sub tropical and equatorial belts across Africa

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and Asia, showing markedly positive change rates in the 1992 to 2013 period.".

Page 9 L8-9: what do you mean by "global sustainability levels of river systems"?

This concept should be linked to human pressure, but we realized that it may be misleading. In our revised manuscript we will remove it and keep only "human pressure on river systems".

L11: "in the near future" seems redundant and overly restrictive.

This will be deleted in the revised version of the manuscript.

L12: "objective and powerful" seem both to be subjective and redundant. Personally, I would let the reader conclude this, rather than make this conclusion for them.

Ok, thanks.

L11-13: "The Differential Human [. . .] needs to be taken" is not a logical sentence. Please rephrase.

This sentence will read: "The Differential Human Pressure on Rivers index (DHPR) proposed here is a simple tool that analyzes for the first time the temporal evolution of human pressure on river systems. DHPR identifies hot spot areas of change, offering guidance on where implementing mitigation strategies."

L13: "identifies areas where priority action needs to be taken" should be removed.

Please refer to our previous reply.

L17: Nightlights and river discharges are [considered] the sole controlling drivers of human pressure on river systems. (add the word considered).

Ok, thanks.

L18: "have been proven", not "have been proved".

Ok.

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L17-26: I appreciate that these limitations are discussed. However, I think it is much more relevant to point out the limitation that nightlight data can have very little to do with human pressure on rivers, and is a largely unvalidated proxy for this.

Thanks for this comment. Our original goal here was to simply highlight the technical limits of the data employed in our study. In the revised version we will comment also on this issue. For more details, please refer to our reply above.

L24: these action wont "cast some doubts on nightlight values", they will "cast some doubts on to what extent nightlight values represent the changes you are interested in here".

Thanks for this. The sentence will read: "In addition, light pollution abatement strategies employed to reduce the artificial sky brightness and preserve world's ecosystems, can cast some doubts on nightlight values and on their evolution in time."

L32: The following statement seems at odd with a study that focusses on human pressure on rivers "Furthermore, given that our focus is on natural river systems, [. . .]"

We respectfully disagree. As an initial research, we preferred not to introduce any additional drivers that could influence (and eventually confound) our estimates of human pressure on rivers. Future research will definitely focus on this.

Page 10 L10: I am unsure what "an order zero information" means

Thanks for this remark. In the revised manuscript we will change "an order zero information" in "simplified information".

L12-13: "Our study identifies critical zones where the change rate of human pressure will undermine human security and sustainable development in the near future." This statement is unfounded and seems like an overinterpretation of the results. Undermine human security? Sure, your results can be related to limited water resources, but your statement is not shown by any of the results that you have.

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Thanks for your comment. The sentence will be toned down.

Page 13 Vorosmarty" should be "Vörösmarty

Ok.

Page 15 In the figure, F overline should be in italics?

Yes.

Page 16 Figure 3: In the titles of the subpanels: DHPR should be in units % per yr?

Yes, thank you.

Complete captions of figures:

Figure R1. Standardized human pressure on rivers: preliminary results using time varying discharge data to compute the evolution of human pressure on river systems across four catchments in China and Myanmar. A comparison with constant discharge values is also shown.

Figure R2. Global distribution of (a) relative change in human pressure on river systems, DHPR (% per year), (b) long term average standardized human pressure on river systems, $\overline{F}$, where the value at the outlet is uniformly distributed across each river basin, and (c) the absolute change in pressure (% per year), as the product between DHPR and $\overline{F}$.

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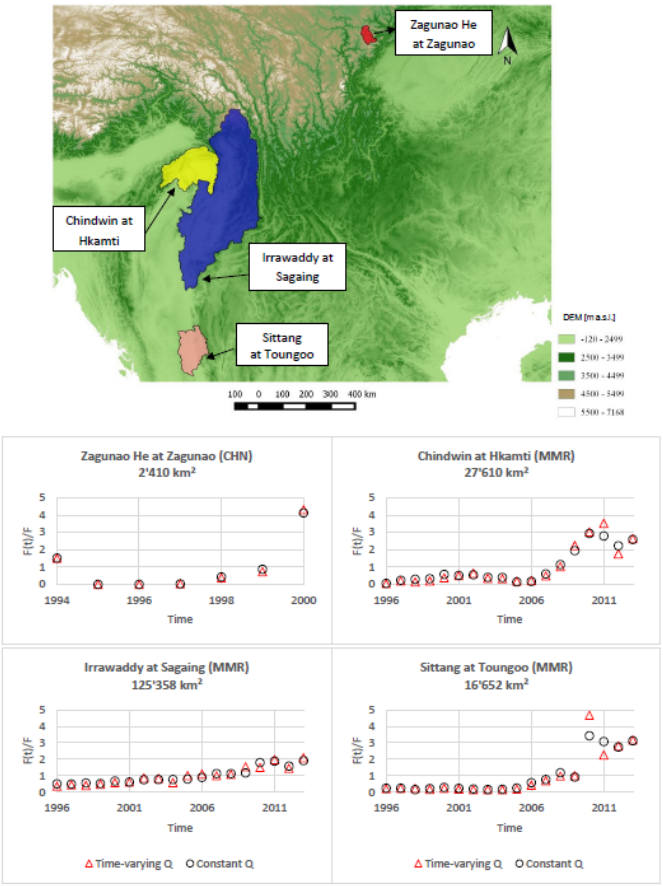

Fig. 1. Standardized human pressure on rivers: preliminary results using time varying discharge data to compute the evolution of human pressure on river systems across four catchments in China and Myanmar.

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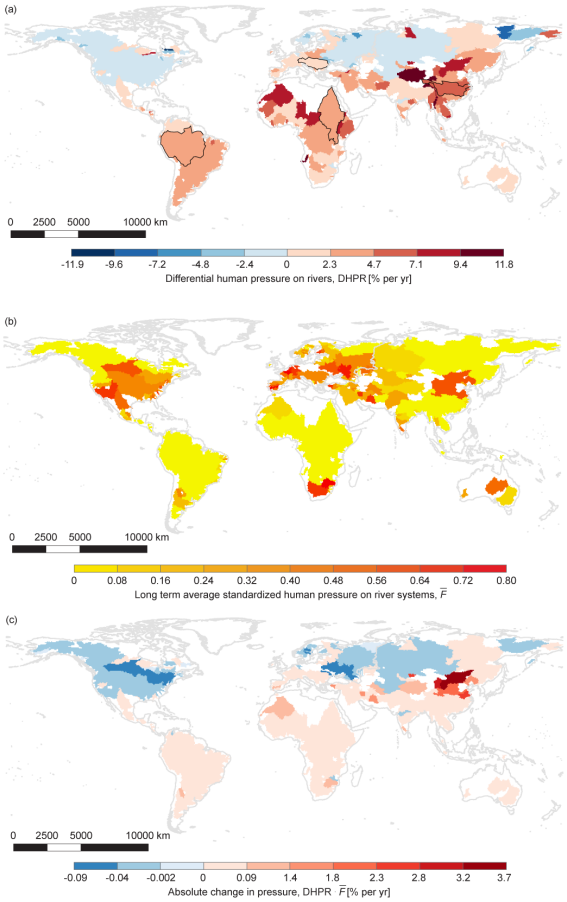

Fig. 2. Global distribution of (a) relative change in human pressure on river systems, DHPR (% per year), (b) long term average standardized human pressure on river systems, F, where the value at the outlet

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