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Review of the doctoral thesis by Mr. Mohammadreza Einikarimkandi, entitled
„Enhancing the accuracy of process-based and data-driven models for predicting drought"
(Poprawa dokładności predykcji suszy
za pomocą modeli opartych na procesach i modeli opartych na danych)
prepared under the academic supervision of dr. hab. Mikołaj Piniewski, prof. SGGW in the Department of Hydrology, Meteorology and Water Management,
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1. Introduction

This review was prepared on the basis of a letter dated May 6th, 2024 from the Chairman of the Discipline Council of environmental engineering, mining and energy, Prof. dr. hab. inż. Janusz Kubrak.

Pursuant to art. 221 para 10 of the Higher Education and Science Act dated 20 July 2018 (Polish Journal of Laws of 2018 item 1668, as amended), a PhD thesis prepared under the direction of an academic supervisor should be an original solution to an academic problem, demonstrate the candidate's general theoretical knowledge in a given academic or artistic discipline, and his/her ability to conduct independent academic work. Taking these requirements into consideration, the following criteria were adopted for assessing Mr Mohammadreza Einikarimkandi's doctoral thesis:

- Evaluation of the original solution to the academic problem;
- Evaluation of the author's general theoretical knowledge on issues related to the Discipline of environmental engineering, mining and energy;
- Evaluation of the author's ability to individually conduct academic research.

The submitted doctoral thesis consists of 128 pages including 37 pages of text supported by five publications:

- Eini, M. R., Ziveh, A. R., Salmani, H., Mujahid, S., Ghezelayagh, P., & Piniewski, M. (2023). Detecting drought events over a region in Central Europe using a regional and two satellite-based precipitation datasets. Agricultural and Forest Meteorology, 342, 109733. https://doi.org/10.1016/j.agrformet.2023.109733
- Eini, M. R., Rahmati, A., & Piniewski, M. (2022). Hydrological application and accuracy evaluation of PERSIANN satellite-based precipitation estimates over a humid continental climate catchment. Journal of Hydrology: Regional Studies, 41, 101109. https://doi.org/10.1016/j.ejrh.2022.101109
- Eini, M. R., Salmani, H., & Piniewski, M. (2023). Comparison of process-based and statistical approaches for simulation and projections of rainfed crop yields. Agricultural Water Management, 277, 108107. https://doi.org/10.1016/j.agwat.2022.108107
- Eini, M. R., Massari, C., & Piniewski, M. (2023). Satellite-based soil moisture enhances the reliability of agro-hydrological modeling in large transboundary river basins. Science of the Total Environment, 873, 162396. https://doi.org/10.1016/j.scitotenv.2023.162396

– Eini, M. R., Najminejad, F., & Piniewski, M. (2023). Direct and indirect simulating and projecting hydrological drought using a supervised machine learning method. Science of The Total Environment, 898, 165523. https://doi.org/10.1016/j.scitotenv.2023.165523

The doctoral thesis consists of 13 sections, eight of which summarize the undertaken studies on drought phenomena including 'Modeling approaches in drought assessments' (section 1), 'Research objectives and hypotheses' (section 2), 'Materials and methods' (section 3), 'Results' (section 4), 'Discussion' (Section 5), 'Conclusion' (Section 6), 'Other achievements' (section 7), 'References' (section 8). The sections from 9 to 13 include five published aricles, all of which belong to the highly-ranked journals within the scientific discipline of environmental engineering, mining and energy included in the list of the Ministry of Science and Education. The impact factor for the *Agricultural and Forest Meteorology* is 6.2 (MEiN: 200 points), for the *Agricultural Water Management* – 6.7 (MEiN: 140 points), for the *Journal of Hydrology: Regional Studies* – 4.7 (MEiN: 100 points), for the *Science of the Total Environment* – 9.8 (MEiN: 200 points). Mr Mohammadreza Einikarimkandi was the first Author of all above mentioned publications and his contribution comprised conceptualization, methodology, software, validation, writing (original draft, review and editing), and visualization. The information about the individual contribution of each co-author is included; it is confirmed Mr Mohammadreza Einikarimkandi is the leading Author of the published articles.

2. Evaluation of the original solution to the academic problem

This thesis focuses on the use of different agro-hydrological modeling techniques to improve the understanding and prediction of various types of droughts, including meteorological, hydrological and agricultural aspects of such hazard phenomena. Three specific objectives have been formulated:

a) Improving the accuracy of agro-hydrological process-based and data-driven models for predicting drought;

b) Assessing the changes in different types of drought in Poland;

c) Evaluating satellite-based datasets in agro-hydrological applications.

The research hypothesis is accurately formulated; it states that „the accuracy of agro-hydrological modelling can be enhanced by utilizing multi-objective calibration approaches and input data from satellite-based datasets."

The issue of drought modelling and predicting addressed in this thesis has key importance for the advancements in environmental engineering both in the theoretical and practical aspects. For decades, methods to improve calibration and validation approaches have been already investigated. Some studies focused on the role of objective functions and parameter uncertainty in the calibration process. Calibration of the conceptual rainfall-runoff models based on continuous daily discharge data has long been common technique in hydrological investigations and continues to be applied in current studies. However, there is a widespread consensus in the hydrological community on the need for additional environmental datasets to be employed in the calibration procedure, complementing discharge observations, to correctly represent additional relevant hydrological variables and processes of the water cycle. Calibrating against daily discharge observations is a primary objective but might be not sufficient to properly simulate internal model variables and physical processes in hydrological systems like watersheds. Only recently, multi-dataset calibration has become more common practice. Thus, there is a clear need for more research using such an approach which should be applied in various regional investigations. An assessment of drought phenomena is particularly important in the face of climate warming, increasing anthropogenic pressure, as

well as the need to develop adaptation strategies related to the sustainable management of limited water resources. This dissertation fits into these topics. It is an advanced type of modern hydrological research with all the features of a doctoral thesis, representing high scientific level. More precisely, this research has made a great step forward by assimilating various types of data (ground-based gridded daily climate dataset – G2DC-PL+, satellite-based precipitation datasets – SM2RAIN-ASCAT, CCI (Climate Change Initiative) Soil Moisture dataset, and river discharge data) into hydrological modeling. Moreover, two types of hydrological modeling have been applied applied, namely process-based modeling and the data-driven modeling.

When using standardized indices of precipitation (SPI-3 to SPI-12), the accuracy of datasets for monthly precipitation estimates and drought monitoring was evaluated against a regional gridded dataset (**Publication 1**), all within the spatial domain of the territory of Poland. When using the Soil and Water Assessment Tool (SWAT+) model, which is an agro-hydrological process-based model (**Publication 2**), PERSIANN family satellite-based precipitation datasets were evaluated against a regional gridded dataset over the Wełna river catchment in Poland. The modeling involved the calibration and validation of the SWAT+ model with the G2DC-PL+ dataset used as a reference dataset, and then the PERSIANN family products were used. Important conclusions were derived concerning the reliability of daily precipitation estimates in runoff simulations. In **Publication 3**, a comparison of the historical crop-yield simulation was assessed using process-based and statistical approaches in a medium-sized catchment in north-western Poland. Again, the Soil and Water Assessment Tool+ (SWAT+) model was applied, and additionally, a data-driven model, Feed Forward Back Propagation Neural Network (FFBPNN) was employed. The novelty was achieved by adding a meteorological drought index as an additional input parameter to the FFBPNN which improved the accuracy of the crop-yield estimates. Important conclusions were drawn on the crop-yield projected to change very little under future climate. Important question for future consideration was formulated at the end, whether such sophisticated modeling techniques show a „different pattern than those obtained using a simple delta change method failing to take into account changes in climate variability and extreme events". In the fourth article (**Publication 4**) agro-hydrological modeling in large transboundary river basins was enhanced by employing the satellite-based soil moisture to the input variables. The Author states in the Abstract of Doctoral Thesis (Page 7) that the transition from single-objective to multi-objective calibration approach evidently improved the precision of river discharge and reliability of crop yield estimates. Important to notice is that Figure 2 of the Publication 4 (Page 6) shows that ten of twenty six river gauges (38%) was marked by reduction of the model accuracy in runoff simulations as evaluated by the Kling–Gupta efficiency (KGE), and only sixteen gauge stations achieved improvements in flow accuracy. The accuracy reduction is probably small, which allows the simulations to be considered correct, but the question arises as to what the causes of these differences are. I would like to ask the Doctoral Candidate to answer this question during his defense. The second question concerns the results of crop yield simulations: can we talk about reliability improvement of crop yield estimates if "the correlation between the simulated crop yields and observed data is not acceptable" (Publication 4, Page 8). Next article (**Publication 5**) concerned the hydrological drought evaluated by the Standardized Runoff Index (SRI). This drought index was simulated and projected using Artificial Neural Networks (ANNs) employing maximum and minimum temperature, precipitation, and Standardized Precipitation Index (SPI)) selected as predictors. A direct approach (directly simulating and projecting SRI) and an indirect approach (simulating and projecting river discharge, then calculating SRI) were compared. The indirect approach performed better than the direct approach in simulations of SRI in four discharge stations in the Odra River Basin (a

transboundary river basin in Central Europe) from 2000 to 2019. The applied methods were suitable to prove that ANN has a high accuracy in runoff and drought simulations, meteorological drought indicator (i.e., SPI) can be used as a predictor of runoff and hydrological drought; and future droughts are expected to become more frequent and more severe than those in the historical period.

Summarizing, all applied methods involved highly advanced drought-modeling techniques introducing original solutions to the formulated problem. The novelty lies in providing the effective and variant techniques replicating various processes in hydrology, agriculture, and meteorology.

3. Evaluation of the author's general knowledge on issues related to the field of Environmental Engineering

Mr's Mohammadreza Einikarimkandi doctoral thesis confirmed extensive knowledge, summarizing professional experience gained as a result of focused research in the field of agricultural hydrology and hydrology within the discipline of environmental engineering. The subject and purpose of the research were clearly formulated. The work contributed to the main-stream, modern research on meteorological, hydrological and agricultural drought. The conclusions have been well documented, are logical and very valuable from a cognitive perspective. The work addressed a number of methodological problems. One of the most important was the development and testing of the possibility of using multi-datasets as determinants responsible for the hydrological system behavior. The thesis clearly goes beyond fundamental knowledge, thus it witnesses the interdisciplinary foundation of the dissertation. I have no doubt that the Author has such broad knowledge in order to plan, carry out necessary research, draw conclusions, and finally incorporate this entire process in the presented academic thesis.

4. Evaluation of the author's ability to conduct independent academic research

The presented doctoral thesis is based on the articles published already in the highly-ranked academic journals belonging to the discipline of environmental engineering. I rate the presented doctoral thesis highly as it is outstanding in terms of the research methods developed and used. It contains original solutions, and the candidate's theoretical, methodological and general knowledge in the field of environmental engineering is, in my opinion, sufficient to conduct independent academic research. As a first Author of all presented articles, Mr Mohammadreza Einikarimkandi worked independently to design the research, conducted the investigations, and finally reported the results in a formal way. Moreover, Mr Mohammadreza Einikarimkandi effectively cooperated with co-authors, to effectively present the research results to the broad scientific community. Besides the doctoral thesis, Mr Mohammadreza Einikarimkandi actively participated in the outstanding international and local conferences, and – in the investigations on water accounting, groundwater management and modeling, water saving plans at the basin level, and extreme hydrological events.

5. Summary and conclusion

The overall evaluation of the thesis entitled „Enhancing the accuracy of process-based and data-driven models for predicting drought" leads to my conclusion that it represents a high standard and significantly broadens knowledge in the field of environmental engineering. The PhD Candidate demonstrates His ability to originally formulate and solve a research problem and His general theoretical knowledge in the field of environmental engineering is broad. This work also demonstrates that the PhD Candidate is able to conduct independent academic

research. The Doctoral thesis is outstanding taking into account such criteria as originality, rigorous research, clear articulation of research questions and objectives, robust methodology, significant findings that contribute to new knowledge to the field, accuracy, and rigorous organization.

Therefore, I acknowledge that this thesis meets the statutory requirements and may constitute the basis to confer a PhD degree in the Discipline of environmental engineering, mining and energy, pursuant to art. 221 para 10 of the Higher Education and Science Act dated 20 July 2018 (Polish Journal of Laws of 2018 item 1668, as amended). I request the doctoral committee that this thesis be permitted to be defended publicly**.** At the same time, I request the doctoral committee to propose to the Discipline Council to award a distinction for a particularly high scientific level of the doctoral thesis, which has exceptional methodological and practical significance.

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Elektronicznie podpisany przez Urszula Somorowska; UW
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