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DISCUSSION

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Evaluating the structures and arrangements of water institutions to include in-stream modeling for water quality management and control pollution: Insights from the Awash Basin, Ethiopia

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Abstract

Healthy rivers and stream waters support sustainable use and protect the ecological health of water flows. Developing countries rarely include in-stream water quality modeling in their strategic policy documents. In the sub-Saharan regions, stream water quality is declining due to many human activities. Ethiopian is no different, and its environmental policy does not directly target the importance of impact and planning analyses. Also, it does not include decision making processes for the protection of water ecology and multiple water uses. In this study, stream water quality issues in the Awash Basin have been assessed. The key sources of land-based pollutants have been identified, and the availability and appropriateness related data have been examined and evaluated as well as the capacity of model users of institutions. Applicable models with the capability of simulating the Awash streams are presented and the changes needed for the existing settings suggested. The model selection was undertaken using a set of criteria based on environmental assumptions to enable environmental improvement into the future. The available hydrological and monitoring information provides an opportunity to apply model analyses, while the poor capacity of the governmental model users is of concern. With limited supporting conditions in governmental water institutions, the level of in-stream water quality modeling integration in the Awash Basin development plans is too low to make recommendations based on key areas of support. It is time to apply and capitalize on the potential opportunity of using the models in local, regional, and national institutions for planning and impact analyses and strategic policy documents. The methods described in this study can be a guidance for model practitioners of the Awash basin targeting improvement in their institutions.

KEYWORDS
water and the environment

1 | BACKGROUND AND POLICY NEXUS

Unregulated waste discharges and poor law enforcement have exacerbated the problems of water quality in the Awash Basin. Though the basin's streams have relatively high economic significance, improvement measures are scarce, and the application of modeling tools for water quality management is poor (EMoWIE, 2016). This is due to lack of adequate water quality information for impact and planning analyses and decision-making processes (Arnold et al., 2015; Zinabu et al., 2017). To support informed decision and meet regulation standards for stream water qualities, it is necessary to handle and process available data/information and apply water quality models (el Khoury et al., 2021; Jin et al., 2021). Since water quality modeling simulating pollutant transport in streams (commonly named as "in-stream modeling") vary with their data needs, assumptions, and process types, the best approach is to find an applicable model for the issue of concern (Kannel et al., 2011; Loucks & van Beek, 2017). In the Awash Basin, several governmental institutions are tasked with water quality management and policy. In addition to the federal and regional institutions engaging in water quality management and protection of streams, the Awash Basin Administration is responsible in administrating the water resources and tackling issues with the hydrology and water quality of the basin. However, almost all institutions conventionally focus on statistical analyses of monitoring information. They are neither acquainted enough nor apply water quality modeling for impacts analyses and planning in their decision process. There are no institutional structures to organize water quality data, and most of them have no or minimal water quality modeling capacity. Since the institutions are engaged in different functions, they need different water quality model analyses depending on their setting. Those institutions working on policies and guidance need to perform in a water quality modeling setting with advanced infrastructure. In contrast, this may not be needed in the other institutions such as those working in compliance information and local environmental conditions.

2 | METHODOLOGY

2.1 | Data collection methods

The key considerations that have been taken in account in this study are as follows: first, identify the potential land-based pollution sources into streams, specifically from diffuse sources of the existing land cover/land uses and surficial geologies, and also, industrial point sources. QGIS, which is a freeware GIS package (QGIS Development Team, 2009), was used to process spatial characteristics including basin boundaries, land covers, geology, pollutant sources, and monitoring and hydrological information. Second, assessing the available data and information sources for water quality modeling was done so as to identify input data and gaps for in-stream water quality model usage. This has been undertaken through identification of pertinent information and data sources in water institutions and evaluation of their capacity to apply water quality models. Initial scoping interviews and semi-structured interviews were used. A targeted literature review has been undertaken to collect the related information and understand the water quality management issues in the Awash basin. Here, the attention was given to the governmental institutions, as they are the most stable and long-lasting operating units in terms of WQ management. The acquired information was checked for in-stream model needs, and, also, knowledge and skill gaps in the institutions were assessed. Third, the applicable model was selected from six free and open-source models that are currently used in most countries. Setting criteria for model selection was done to screen the best applicable model. Furthermore, the selection of the criteria was supplemented by the users' responses to the questionnaires and interviews. The product of these considerations is used to present options of models specific to the conditions of the Awash basin and indicate structural and arrangement changes needed as a policy implementation strategy in water institutions.

2.2 | Data analysis

QGIS was applied to analyze the spatial distributions of land covers, surficial geologies, monitoring and hydrological stations, industries, and other catchment information including mapping of stream networks and catchment boundary (QGIS Development Team, 2009). The Copernicus Global Land Service, which is providing bio-geophysical products of global land surface of high-quality sentinel-2 images, was processed in the QGIS to derive the land covers of the basin using the UN-FAO's Land Cover Classification System (LCCS) (Buchhorn et al., 2019). Tabular outputs were used to evaluate the capacity of the water institutions in operating water quality modeling. A scoring system was applied to determine the best applicable models based on the set of criteria for model selection.

3 | FINDINGS OF INFORMATIONAL DATA AND INSTITUTIONAL ISSUES TO SET OUT MODEL SELECTION

3.1 | Land cover, surficial geology, and industry as pollution sources

The Awash Basin is dominated by cropland and herbaceous vegetation (~42%) (Figure 1). These land covers are in constant change from human activities of growing crops and herding cattle, respectively. Additionally, large parts of the cropland and urban areas are near and within the riparian buffers, especially in the upper and middle parts of the basin. This enables transfer of anthropogenic source of diffuse pollutants into nearby streams. According to the Copernicus Global Land Service, drastic land cover changes had been seen in the basin between 2015 (Figure 1a,b) and 2019 (Figure 1c,d), amounting to 1,320.08 km^2. Notably, the decrease in forestland and herbaceous vegetation increases the loss of diffuse pollutants (such as nutrients) from retention processes and, thereby, increases the transfer of more pollutants into streams via rapid runoff processes (Kang et al., 2010; Whitehead et al., 2018).

Similarly, based on the USGS global geology map (Soller & Berg, 2005) BIBLIOGRAPHY \l 2057, the Awash Basin is composed of varied surficial deposits with different chemical compositions

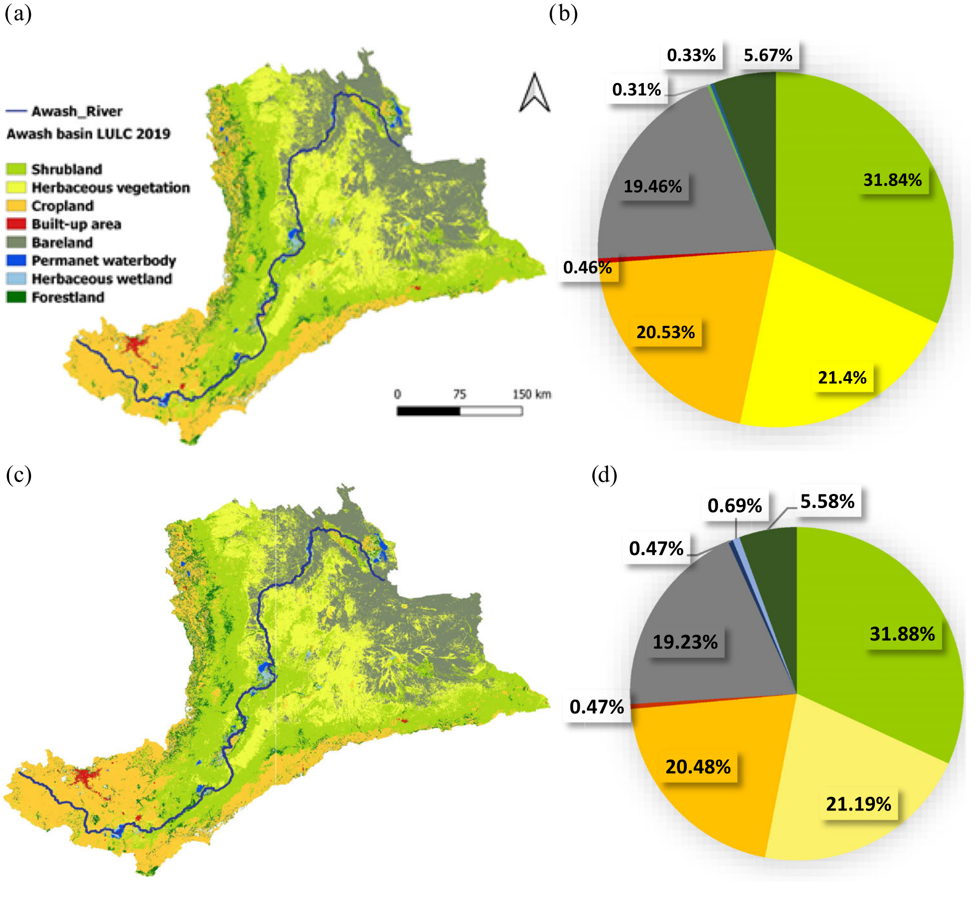

FIGURE 1 The Awash basin's land covers (a, c) and their percentages distributions (b, d) in the years of 2015 and 2019 (based on the Copernicus Global Land Service image products; Buchhorn et al., 2019).

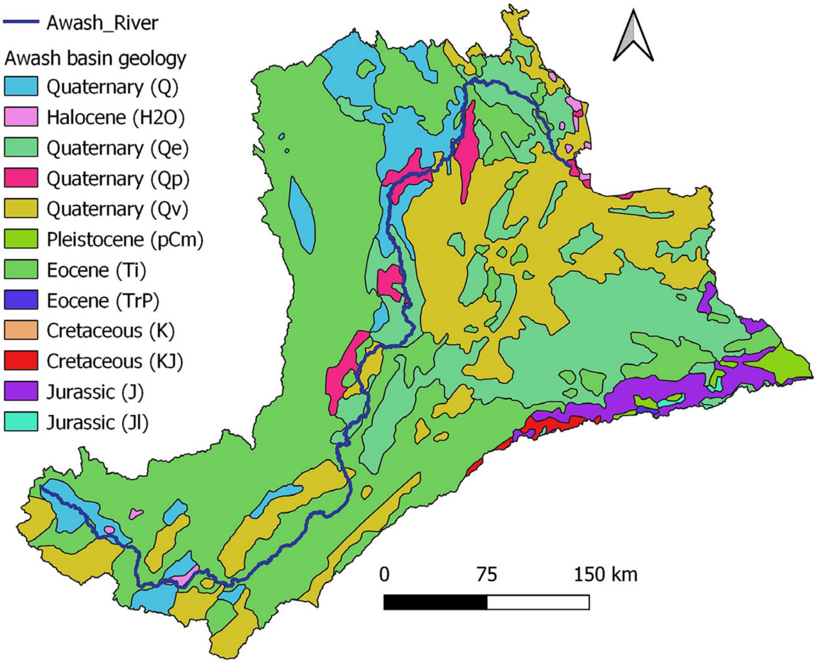

FIGURE 2 Surficial geology of the Awash Basin ordered in increasing age (listed in the legend); the map was derived from the USGS global geology map (Soller & Berg, 2005).

(Figure 2). The larger part of the basin is Eocene surficial geology, also, with considerable cover of Jurassic and Quaternary deposits that are mainly composed of poorly consolidated clay, silt, sand, or gravel-sized particles. The Awash River system crosses the Eocene and quaternary geologies (Figure 2), and these geologies can be associated with different chemical compositions and the base flows of streams. It can also lead to different water qualities at different geographical locations. Besides, these geologies are exposed to flooding, erosions, and landslides and thus, are important characteristics that can influence stream water quality (Panno & Hackley, 2010).

There are many industries along the main stream of the Awash Basin (Figure 3a). The larger proportions of them (i.e., 86%) are established in the upper Awash Basin, specifically in the areas between the capital city of Addis Ababa and the town of Modjo (Figure 3b). Many pollutants are derived from these point sources, as they comprise different manufacturing processes. There are more tanneries, textile, and detergents factories, which are known to contain toxic chemical in their effluents and unregulated effluent discharges from these pose a considerable threat to the water quality of the receiving streams.

3.2 | Obtainable data/information for modeling

There are many hydrological monitoring stations along streams of the Awash Basin. The stations are mainly operated by the Ministry of Water and Energy and the Awash Basin Administration. Currently, about 60 stations are functional, and most of them are placed in the upper and middle Awash Basin (Figure 4a). In contrast, for water quality monitoring, only 39 stations are available and the majority of them are found in upper and middle parts of the basin

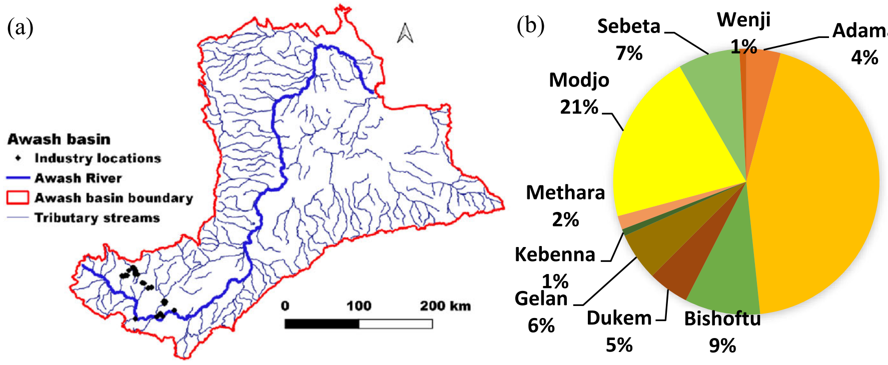

FIGURE 3 The location of industries in the Awash Basin (a), and their apportionment (%) by their local administration place (b).

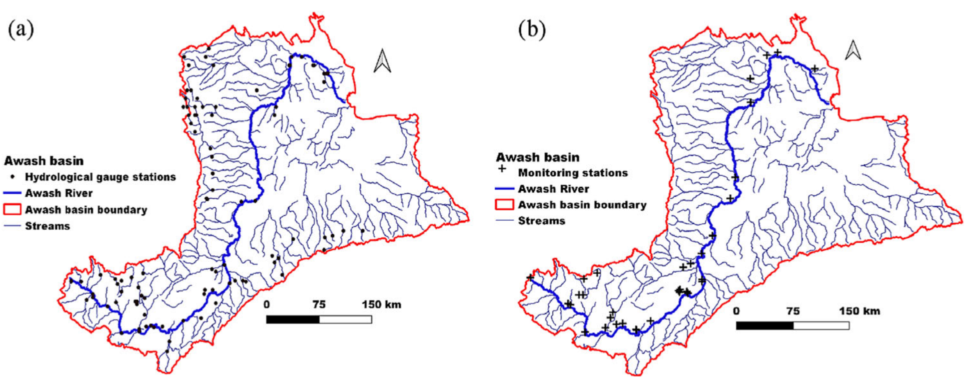

FIGURE 4 The distribution of hydrological (a) and monitoring stations (b) in the Awash Basin.

(Figure 4b). In some stations, both the hydrological and water quality monitoring are being undertaken. Remarkably, several remote hydrological stations are located in north-west of the basin, though no water quality monitoring stations are available for the streams.

3.2.1 | Institutions' competency and access to water quality modeling

An investigation has been conducted on the role of water quality modeling in seven governmental institutions (see the supporting information). The institutions tasked with informing water quality and management were targeted and evaluated for their competency and access to monitoring information related to the application of water quality modeling. The institutions can generally be categorized as public water administration, or water services and research. It was found that most of the institutions are monitoring the physical and chemical characteristics of streams, and only two institutes were conducting biological monitoring. Most of the institutes monitor streams to check the quality of the streams for drinking and irrigation water uses and not necessarily for pollution control reasons.

The water institutions and their experts were also evaluated in relation to their access and expertise to operate in-stream models (see the supporting information). Given poor financial

TABLE 1 Out of seven institutions, the number of competent regional and federal institutions in terms of database centers, trained staffs (both in knowledge and skills) to operate in-stream modeling.

S/n	Characteristics	No capacity	Minimal capacity	Moderate capacity	Advanced capacity
1	Database infrastructures	1	6	-	-
2	Monitoring	2	3	2	
3	Users				
3.1.	Knowledge	2	4	1	-
3.2.	Skills	6	1	-	-

resources in developing countries, the users have been evaluated as to whether they have access to modeling tools and have the necessary skills and infrastructure at their institutions (Darji et al., 2022). Accordingly, availability of monitoring stations; level of training of the person performing the modeling (knowledge and skills); and infrastructure (database facility) of seven institutions were evaluated (Table 1). The institutions' main source of water quality information was personal records, communication, and internet sources. The identified gaps in water quality data provision consisted of absence of database management and sharing system, lack of budget for data center services and electronic resources, incomprehensive and not up to date information, and insufficient training in searching and using data and information. Though it was found that the institutions have their own monitoring stations, most of them have no database.

3.3 | Screening the best applicable model

To find the best applicable model matching the present circumstances of the Awash Basin, we considered globally available in-stream models for screening the best applicable model. The commonly used water quality model selection process has been proposed by US EPA (Ejigu, 2021). However, for the Awash Basin, it was proposed to select the public (i.e., free available) models so as to avoid this limitation. Accordingly, six in-stream models were considered for screening the applicable one: (1) INCA (Integrated Catchment) (Whitehead et al., 2018, 2021, 1998), (2) WASP8 (Water Quality Analysis Simulation Program) (Ranjith et al., 2019), (3) QUASAR (Quality Simulation along Rivers) (Cox, 2003; Ranjith et al., 2019), (4) QUAL2KW (Bui et al., 2019; Chapra et al., 2015; Pramaningsih et al., 2020), (5) CE-QUAL-RIVI, and (6) SIMCAT (Simulation of Catchments) (Cox, 2003; Ranjith et al., 2019).

The screening of the feasible in-stream model was predicated on seven criteria (see Table 2). The criteria were prepared in view of the currently modeling experiences in the Awash basin and enabling an improvement in the future (Angello et al., 2021; Bussi et al., 2021; Keraga, 2019). The streams in the Awash basin are usually small and shallow, and the greatest water quality gradients generally occur along the flow axis, and thus, one-dimensional (longitudinal) models that employ cross-sectional averaging are appropriate for simulation. Moreover, starting with one-dimensional mathematical description of steady-state flows helps to reduce model development, simulation, and analyses cost, and it can fit well to least developing countries. Finally, we recommend that QUAL2KW and INCA models are applicable for the present conditions of streams in the Awash Basin.

TABLE 2 Results of the five in-stream models' performances against set of criteria using a scoring system out of 5 points.

S/n	Model criterion	INCA	WASP	QUASAR	QUAL2KW	CE-QUAL-RIVI	SIMCAT
1	Input complexity	4	2	4	5	5	5
2	Simulating multiple pollutants	5	5	4	4	3	3
3	Integration with other models	5	4	3	5	3	4
4	User friendly adaption	4	3	2	5	5	5
5	Compatibility to agricultural source pollution	5	5	5	5	3	5
6	Presence of user manual and documentation	5	5	5	5	4	5
7	Credibility in legal terms	5	5	5	5	5	5
8	Continued improvement and maintenance	5	5	5	5	2	3
	Total score	38	34	33	39	30	35

4 | CONCLUSION

There is a worsening in-stream water quality situation in the Awash Basin, due to increased factory development upstream and land use change downstream, exacerbated by population increase, and enhanced diffuse pollution. The application of water quality modeling is poor across the institutions engaging in water quality managements and regulations. The selection of an applicable model has been evaluated considering the existing water quality issues and assessing the current status of data availability for model application. The key issues to be considered in the modeling are understanding the effect of land cover changes and patterns of catchments in stream water quality, determining the interaction between stream water quality and surficial geologies, and identifying spatially important water quality hotspots in the basin such as ecologically sensitive habitats, protection areas, and reservoirs along streams and an assessment of point and diffuse pollution.

4.1 | Policy implications and recommendations

- It is important to be aware of the policy of governmental units engaged in water quality management, especially in the Awash Basin administration. Furthermore, the Ministry of Water and Energy of Ethiopia needs to be partner in the policy and practice changes.

- With scant river water monitoring stations in the north-west of the Awash Basin, which is a highly industrialized areas, re-alignment of the monitoring strategy by involving local, regional, and federal institutions is vital to meet with modeling requirements, including boundary conditions from tributaries, major diversions such as irrigation and abstraction, and point source discharges.
- In-stream water quality modeling should be used for regulatory purposes especially in the most developed Awash Basin and at a national scale too. This would be support testing of compliance of stream waters against regulatory standards and analyses of regulatory requirements of industrial effluents.
- For the Awash Basin, it is important to focus on simulating the streams water quality and determining the carrying capacity (for pollutants) of the widely water uses such as drinking and irrigation water uses. Furthermore, in-stream water quality modeling can be applied to control accidental spills of industrial wastes into streams or enable emergency disposal of pollutants depending on the problem at hand. This would be particularly useful in the upper Awash where many industries are located nearby the riparian zones of the Awash River and its tributaries.
- Lack of proper infrastructure (such as organized data-based management and sharing systems) and skills in applying are challenges for institutions in the Awash Basin. As a mid- and long-term plans, building the capacity of professions (including at the local government units) and enabling conditions to create own models following a conceptual framework and in situ-measured model parameters should be targeted. In all of the concerned institutes, the outdated and poor data set-up should be changed so as to access stored water quality data and information for model processing.
- The methodological procedure described in the study project can be a guidance for Ethiopia's local model practitioners working in water quality managements both in governmental and non-governmental institutions such as the Awash Basin administration, Oromia and Amhara Water and Energy Bureaus
- Furthermore, it is necessary to build the capacity of institutions to mandate or list some water quality models at regional or nation level so as to guarantee the consistency of water quality models for regulatory purposes such as in environmental impact assessments. The models can be regulated and standardized through validating system, including published articles, workshops, or setting up local workgroups.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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