WHY HYDROLOGICAL MODELLING: SWOT ANALYSIS

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Abstract

Due to exponential changes in climate and land use, spatial and temporal variability in the global water cycle are being reported by many studies. Human activities are affected by rapid social and economic developments, consequently, water has turned into the most demanded resource which leading to severe water shortage around the world. In this research, systematic review method was used to analyze the recent climate and hydrology studies, and besides, SWOT analysis was performed to see Strength, Weakness, Opportunity and Threat of modelling studies, hydrological modelling in particular. The results showed that the studies were carried out in the various river basins, lakes and watersheds, where mostly impact of climate change on water resources was investigated using hydrological models. It was reported that limitation of the modelling were issues with data sufficiency, software skill requirement and misinterpretation of model results by the end users. Moreover, modelling holds some threats that when there is uncertainty in input data that leads overestimated values in model simulation.

Keywords: *hydrological modelling, hydrological cycle, SWOT analysis, climate change, river, reservoirs*

Introduction. Water is considered as a finite resource, which make important role in life of all living organism, and for maintaining and supporting sustainable socio-economic development. However, due to exponential changes in climate and land use, spatial and temporal variability in the global water cycle are being reported by many studies [1]. Besides, human activities are affected by rapid social and economic developments, consequently, water has turned into the most demanded resource which leading to severe water shortage around the world [1, 2]. Clearly, greenhouse gas emission can be one of human activities, which hold great effect on water cycle. According to IPCC (2014), climate change can be characterized by temperature rise, and more frequent extreme events, including heavy rains, floods, sudden droughts, and heatwaves.

The most parts of Central Asian region are located in arid zone, which depends on surface water resources coming from Tien Shan, Pamir and Altai mountains [3]. Low precipitation leads to low water availability in the region, and the region has already been experiencing water shortage, which is key limiting factor for socio-economic development [4]. The most of water resource in the region is used for agriculture production. For instance, in Uzbekistan, around 90-92% of the country`s total water is consumed by agriculture sector, which is quite high than neighbor countries, Kazakhstan and Tajikistan [5]. Obviously, majority of water are taken from transboundary rivers, Amu Darua and Syr Darya, accounted for 80%. Therefore, it makes the country vulnerable to changes in climate and hydrological cycle, which might negatively affect sectors such agriculture, forestry and fishery.

Changes in climate and its influence on water resources, plant growth, sedimentation process in open channels, rivers and reservoirs, crop yield are very complex and heterogeneous [6]. Clearly, it is important to take into account many factors influencing the process when it is intended to investigate impact of climate change or change in water availability in both temporal and spatial scales. It might be a bit challenging for researchers to study all factors at once for long term at different locations[7]. Therefore, modelling tools have been created and proposed, which are being used for many years, to simplify the process and to better understand any event before it happens [8]. However, sometimes, there is mistrust towards modelling studies, which might be due to knowledge gap on how model works [9]. Aligning this, this research intends to review and analyze some of recent model studies and main parameters used in hydrological modelling towards filling existing lack of knowledge about modelling and its importance in scientific research works.

Materials and methods. In this research, systematic review method was used to analyze the recent climate and hydrology studies conducted in China, Germany, Uzbekistan, Kyrgyzstan, Kazakhstan, Tajikistan. In this method, each research paper was analyzed based on followings such as type of hydrological models, study area, main factors, main equations, model inputs, and methods of model correction [10].

Besides, SWOT analysis was performed to see Strength, Weakness, Opportunity and Threat of modelling studies, hydrological modelling in particular. SWOT analysis is considered as framework, which can be used to evaluate internal and external factors, and current and future potential that have positive or negative influence on business, regulation, human life and outputs of scientific activities [11]. In this research, SWOT analysis was performed to see strength, weakness, opportunity and threat of modelling studies in hydrology field. In this case, more than 20 articles were reviewed and analyzed towards identifying positive and negative sides of hydrological modelling. The analysis of the articles was given in the table 1, where study site, climate models, hydrological models, simulation and optimization approaches, periods and results were taken as the main indicators.

Results and Discussions. In the most hydrological cycle and water resources researches, quantitative analysis was performed towards investigating human impact on hydrological cycle and researching changes in hydrological process in land surface under climate change effect. In the recent hydrological studies, quantitative analysis was done using different hydrological models, in which better understandings of anthropogenic impact on water availability, climate change and sedimentation process in the reservoirs can be obtained [1]. However, sometimes, modelling of hydrological events can be difficult due to model type, required data (availability and access), study areas, and calibration, validation process. Clearly, hydrological models can be distinguished as following: predictive models can answer to specific problems, and investigative models towards better understand of hydrological process and its interaction with climate, soil, biodiversity and crop yield [12]. It is stated that investigative models require data, which are simple in structure and esitmates.

Data requirement is diverse in different hydrological models. If mode is intended to simulate impact of climate change on water resources in certain location, long term historical climate data can be required towards observing frequency, duration and intensity of hydrometeorological events [13]. It is reported that hydrological parameters, water depth, groundwater, suspended sediment, precipitation, surface temperature and evapotranspiration, have pivotal role in the accuracy and reliability of hydrological simulations [14]. With this, forthcoming issues in extreme water management, policy-making, water allocation and sustainable water resource management are identified and solved. Furthermore, the scenario modelling was also considered as one technique of hydrological simulation, where changes in water discharge is assessed under climate change. In the most hydrological studies, potential evapotranspiration was calculated from daily temperature, relative humidity, wind speed and solar radiation using the Penman-Manteith equation [15].

Table 1. Hydrological studies conducted using models in different locations around the world (Compiled by the authors)

Table 1.

Hydrological studies conducted using models

Authors	Study site	Climate models	Hydrological models	Periods	Main results
Usmanov et al., 2016	Chirchik River Basin, Uzbekistan	Observed climate data (UzHydromet)	MIKE SHE	2009-2013	Evapotranspiration was found to be the main water loss factor among water balance components, with an average of 821 mm/year (77% of the total water budget). Estimated groundwater recharge varied between 180 - 221 mm/year, making up 17% - 20% of the total water budget.
Uzbekov U et al., 2021	Ugam River Basin, Uzbekistan	CMIP5	SWAT	2019-2048	The stream discharge is expected to decrease by approximately 42% within thirty years, with a 1.4 °C increase in temperature and 286 mm decrease in precipitation. The peak point for the future period is 40.32 m^3/s in 2037 whereas the lowest discharge, predicted for 2048, accounts for 22.54 m^3/s.
Gulakhmadov et al., 2020	Vakhsh River Basin, Tajikistan	CMIP5	SWAT	2022-2060 2061-2099	An increasing tendency of average annual streamflow, from 17.5% to 52.3% under both RCPs 4.5 and 8.5, by the end of 2099. A shift in the peak flow month was also found, i.e., from July to June, under both RCPs.
Ongdas et al., 2020	Yesil River Basin, Kazakhstan		HEC-RAS	2017	Comparison of different mesh sizes (25, 50 and 75 m) for the simulation of the event from 2017 demonstrated no significant difference in terms of model performance between different model versions.
Wortmann et al., 2022	Tarim River, China/Kyrgyzstan	WATCH, AHPRODITE	SWIM-G WASA	2011-2040 2041-2070 2071-2100	Depending on the low, medium or high emission scenarios, temperatures are projected to rise by about 1.9 °C, 3.2 °C or 5.3 °C in the ensemble mean by the end of this century (2071–2100) compared to the 1971–2000 reference period, while precipitation may intensify by about 9%, 14% or 24%, respectively.
Uwamahoro et al., 2021	Issyk-Kul, Kygyzstan	Observed climate/MODIS snow data	SWAT	2015-2016	After modifying the model, the flood peaks increased for A and B by 49.42 and 43.87%, respectively, bringing them closer to the reality of the observation discharge. The contributions of snowmelt to stream flow increased by 24.26 and 31% for A and B, respectively.
Willkofer et al., 2018	Mindel River Basin	CCLM4.8 RACMO REMO	WaSiM	1971-2000 2021-2050	The long term yearly flow regimes of the CCLM and REMO differ from the reference. However, apart from the winter season, the raw RACMO model shows a good regime representation. For the Mindel catchment, the different correction approaches account for good adjustment of the modeled runoff to the reference of observed data when applied to raw CCLM and REMO data

According to the table 1, different hydrological models were employed to simulate the response of hydrological cycle to climate change, land use changes and environmental degradation. Accordingly, the studies were carried out in the various river basins, lakes and watersheds, where mostly impact of climate change on water resources was investigated using hydrological models, such as MIKE SHE, SWAT, HEC-RAS, SWIM-G, WaSiM (Table 1). In the studied we reviewed, impact of future climate change was researched and made prediction of its impact on water availability and human life. In the study conducted in Chirchik River Basin, MIKE SHE model was used to investigate change in evapotranspiration and its influence on water balance, where an average of 821 mm/year water loss was found [16]. Another such study was carried out in Ugam River Basin, where impact of future climate change was predicted using SWAT model (Table 1), and accordingly, the streamflow of the basin would decline by roughly 42% within thirty years [17]. In Tajikistan, the same hydrological research was conducted, where the SWAT model was used to see the response of hydrological cycle to climate change for two periods as 2022-2060 and 2061-2099 (Table 1). The results showed an increasing tendency of average annual streamflow, from 17.5% to 52.3% under both RCPs 4.5 and 8.5, by the end of 2099 [18].

According to the results of the SWOT analysis, hydrological modelling has benefits and limitations as shown in the figure 1. Clearly, the strength of modelling is capacity of covering larger spatial and temporal scales, which help to reduce cost of conducting a research. Besides, researchers can simplify complex system using models, and share model outputs with scientific community (Figure 1). The main opportunity that modelling brings are enhancement of scientific knowledge on hydrological cycle and critical thinking of complex system. It was reported that limitation of the modelling were issues with data sufficiency, software skill requirement and misinterpretation of model results by the end users. Moreover, modelling holds some threats that when there is uncertainty in input data leading overestimated values in model results. Another threat is lower model performance due to poor calibration and validation, and in addition, how decision makers accept model outputs can be one of the threats in modelling, hydrological modelling in particular (Figure 1). It was reported that in case of hydrological modelling, more than two or four objective functions (R2 and Nash-Sutcliffe efficiency) and several important parameters should be taken toward improving model performance and accuracy of model outputs.

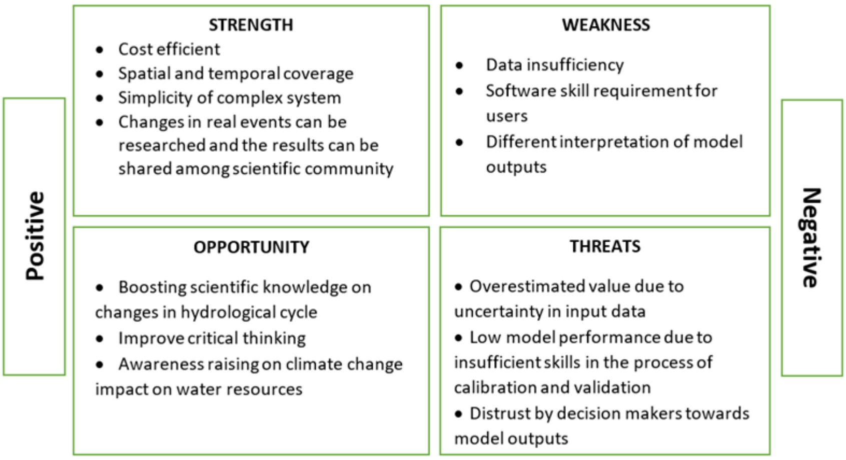

Figure 1. SWOT analysis of hydrological modelling (Compiled by the authors)

Conclusions. It was found that the studies were carried out in the various river basins, lakes and watersheds, where mostly impact of climate change on water resources was investigated using hydrological models, such as MIKE SHE, SWAT, HEC-RAS, SWIM-G, WaSiM. The results of the SWOT analysis showed that the strength of modelling was capacity of covering larger spatial and temporal scales, which would help to reduce cost of conducting a research.

It was reported that the main opportunity that modelling brings were enhancement of scientific knowledge on hydrological cycle and critical thinking of complex system. that limitation of the modelling were issues with data sufficiency, software skill requirement and misinterpretation of model results by the end users. Moreover, modelling holds some threats that when there is uncertainty in input data leading overestimated values in model results. Lower model performance due to poor calibration and validation is another threat.

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