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Application of Soil and Water Assessment Tool in Indonesia – a review and challenges

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A B S T R A C T

Watersheds are increasingly experiencing environmental damage in various parts of the world recently, including in Indonesia. Indonesia, which has approximately 17 thousand watersheds, faces major challenges in watershed management, especially with the increasing pressure on watershed resources. The accuracy of watershed management is very necessary for the era of rapid development and growth. The abilities of Soil and Water Assessment Tool (SWAT) will assist in making the right decisions in watershed management. Although the model has several advantages such as free access and user-friendly, the model still has limitations when applied to watersheds that do not have sufficient observation data. The purpose of this study is to review the uses of this model in Indonesia. The SWAT has been applied in various watersheds reported in 178 publications that have passed peer-review. Most of the applications were found in Java Island, with 112 publications. The availability of climatological and hydrological data was main obstacle for model application. However, remotely sensed data this limitation and challenge can be handled with remote sensing techniques which will make this model very compatible to be applied in Indonesia. The SWAT will expectantly direct its application to regions still less or never been established, such as the Kalimantan and Papua regions.

Keywords: Soil and Water Assessment Tool model; Hydrological modelling; Review; Watershed; River

1. Introduction

The imbalance of the water cycle in a watershed can cause problems for living ecosystems. The potential impact of the imbalance in the water cycle could result extreme flood and drought events [1]. Therefore, watersheds must be properly managed to minimize potential damage to watersheds. One of the approaches in managing watersheds is hydrological modeling [2–4]. Hydrological modeling is a form of simplification of the real hydrological cycle

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system in a watershed that can assist in understanding, predicting, evaluating and managing water resources at the watershed scale [5].

Currently, one of the most well-known hydrological models is SWAT (Soil and Water Assessment Tool) model. The model is a conceptual physically based model that allows simulating a number of different hydrological processes at the same time [6]. It is also a semi distributed model forms the watershed into several small subwatersheds called as Hydrologic Response Units (HRU), in which basic computing elements are then rendered [7]. In principle, a hydrological response unit is a unit area incorporated within a subbasin that comprises a unique combination of land cover, soil and management. Under these conditions, SWAT allows a number of different physical processes to be simulated in the watershed [8].

Before the SWAT model was applied in Indonesian watersheds, this model had gone through a long journey of development. In the early 1990s the SWAT model was developed by combining Simulator for Water Resources in Rural Basins (SWRRB), Routing Outputs to Outlet (ROTO) and Geographic Resources Analysis Support System (GRASS). Since then, SWAT has undergone continuous experience, modification, and improvement. Over the last decade, a number of SWAT models have emerged, adapted to applications outside the US for specific purposes such as SWIM (Soil and Water Integrated Model), SWAT-93, SWAT99.2, SWAT-G model, and ESWAT (Extended Model SWAT) [9]. So far, the dominant uses of this model have focused on model application, model accuracy, and the coupling of this model with other hydrological models or hydraulic models. The model applications were mostly on simulation of runoff, hydrological impacts under environmental change, and pollution from multiple sources [10].

To model the water cycle in a watershed, SWAT requires data or information categorized into climate, groundwater, artificial channels, rivers, and drainage. The ability of the SWAT model is not only able to simulate water quantity, but also has complemented the ability to simulate water quality [11,12]. Water quality parameters that can be simulated include nutrient, $N–NO_3$, nitrogen fluxes [13], and other elements such as sediment and erosion. The SWAT model has also expanded its capabilities in the context of algorithms for erosion and sub-day sediment transport, biozone modules, and new algorithms for simulating shallow groundwater depths [14]. Even in its new development, SWAT developed a new algorithm to improve its capabilities in schedule management operations [15].

As developments have been made for the SWAT model, several researchers have succeeded in using SWAT to handle water quality simulations such as stream temperature. This SWAT model is considered very suitable in estimating the stream temperature [16]. Ficklin et al. [17] have used this model in agriculture field to assess the effect of temperature changes on water yield, irrigation water use, evapotranspiration, and streamflow. Not only in agriculture field, this model has also shown a more accurate performance in fisheries field in simulating stream temperatures in cold water fish habitats using the SWAT model [18].

Other water quality parameters such as nitrate have been successfully simulated with this model [19–21]. Paul et al. [22] used this SWAT model to model nitrogen pollution from various scattered sources. In addition, Lencha et al. [23] also simulated this pollution from two types of sources, namely point and nonpoint sources. The SWAT model is also equipped with a good ability to simulate sediment and erosion [24,25]. So that researchers very often use this model for the needs of sediment and erosion simulations by producing satisfactory model performance [26–28].

Further SWAT model has been successfully developed and used to study various hydrological indicators of flood, drought, land use changes, and climate change impacts [29,30]. The SWAT model has good potential to be applied in case studies in countries around the world and as a tool for analysis that can save time and costs for watershed management [31]. This model can easily be used with a wide selection of calibration and validation techniques [32]. In addition, SWAT is becoming increasingly widely used due to the ease with which the SWAT model interfaces with other applications (e.g., GIS) and have automatic calibration software. This makes it conspicuously easy for less experienced users to get started with SWAT modeling applications [33]. However the calibration manual allows the user to get a better understanding of the overall hydrological process and the sensitivity of the parameters [34]. Furthermore, the structure of the model better reflects the complex controls in simulating the water cycle in the watershed without the need for large computations or complicated parameterization [35].

Regardless of the type of problem that can be solved by SWAT model, the basic concept of water balance adopted within the model is based on the following equation:

$$\mathrm{SW}_t = \mathrm{SW}_0 + \sum_{i=1}^{i} \left(R_{\mathrm{day}} - Q_{\mathrm{surf}} - E_a - W_{\mathrm{seep}} - Q_{\mathrm{gw}} \right) \quad (1)$$

where SW_t is the final soil water content ($mm{\cdot}H_2O$), SW_0 is the initial soil water content on day i ($mm{\cdot}H_2O$), t is the time (d), R_{day} is the amount of precipitation on day i ($mm{\cdot}H_2O$), Q_{surf} is the amount of surface runoff on day i ($mm{\cdot}H_2O$), E_a is the amount of evapotranspiration on day i ($mm{\cdot}H_2O$), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i ($mm{\cdot}H_2O$), and Q_{gw} is the amount of return flow on day i ($mm{\cdot}H_2O$) [8].

Watersheds in Indonesia have experienced various problems such as flood, drought, erosion, sedimentation, and water quality. To anticipate and minimize the damage to these watersheds, the government has made various preventive and recovery efforts. The government of the republic of Indonesia has mandated the Medium-Term National Development Plan (2015–2019) and the Strategic Plan (2015–2019) of the Ministry of Environment and Forestry for handling watershed restoration prioritized in 15 watersheds, namely Citarum, Serayu, Ciliwung, Solo Lama, Brantas, Cisadane, Kapuas, Siak, Musi, Asahan Toba, Jeneberang, Saddang, Moyo, Way Sekampung, and Limboto Bone Watershed.

SWAT model should be an alternative approach to determine the best management practice for water resources in Indonesia's watersheds. The model has shown its performance to provide a reasonable accuracy in areas with tropical climate conditions [36]. In addition, the SWAT model recently has become familiar in Indonesia because it is one of the hydrological models that is very easy to utilize. Therefore, this study aims to review the development and analyze potential prospect of the SWAT model application in Indonesia.

2. Study areas in Indonesia

Indonesia is the largest archipelagic country in the world, located in Southeast Asia. The number of islands owned by Indonesia is 17,508 islands with a total area of 1,904,569 km^2. The main islands of Indonesia are Sumatra Island, Kalimantan Island, Java Island, Sulawesi Island and Papua Island. As the largest archipelagic country in the world, Indonesia is also one of the countries with the longest coastline in the world. The astronomical location of Indonesia is between 6°N to 11°08′LS and 95°E to 141°45′E. Meanwhile, the geographical location of Indonesia is between the continents of Asia and Australia, and between the Indian and the Pacific Oceans. Topographically, Indonesia has different characteristics such as lowlands, highlands, hills, and mountains. The large islands in Indonesia such as Papua, Java, Sulawesi, Kalimantan, and Sumatra have very varied topographic characteristics. The highest point in Indonesia is Puncak Jaya, in Papua, at 4,884 m above sea level, which ranks 28th the worlds' highest point.

Indonesia has three types of climate patterns, namely monsoon, equatorial, and local. Monsoon is the dominant pattern in Indonesia covering almost the entire territory of Indonesia. The equatorial pattern has two peaks of rainfall in period of October-November and March-May. While the local pattern is the opposite of the monsoon. Details of the regional division of climate patterns can be found in the publications of Aldrian and Dwi Susanto [37]. Based on data from 91 observation stations of the Indonesian Agency for Meteorology, Climatology, and Geophysics, the normal air temperature for the 1981–2020 period in Indonesia is 26.6°C whereas the average air temperature in 2020 is 27.3°C. Finally, the average rainfall in Indonesia ranges from 2,000–3,000 mm/y. In Indonesia, 10 soil types have been inventoried from 12 soil type in the world, as a gift of Indonesia's natural wealth including Histosols, Entisols, Inceptisols, Andisols, Mollisols, Vertisols, Alfisols, Ultisols, Spodosols, and Oxisols. There are only two soil types that are not found in Indonesia, namely Aridisols, and Gelisols [38].

The land cover in Indonesia is divided into two types, that is, forest cover and non-forest cover. The land covered with the forest is 33.73% and non-forest is 66.27% [39]. Land cover with forest includes primary dry land forest, secondary dry land forest, primary swamp forest, secondary swamp forest, primary mangrove forest, secondary mangrove forest and plantation forest. Meanwhile, the non-forest land cover consists of bushes/groves, swamp scrub, savanna, plantations, dry land agriculture, mixed dry land agriculture, transmigration, rice fields, ponds, open land, mining, settlements, and air/seaport swamps.

With a population of 270,203,917 in 2020, Indonesia is the fourth most populous country in the world [39]. To support this large population, Indonesia needs a proper watershed management. A watershed is a land area which is a unitary ecosystem of rivers and their tributaries, which functions to accommodate, store, and drain water from rainfall to lakes or seas naturally. Currently, the watershed classification has not reached the stage set which is ratified by the President. However, the Directorate General of Watershed and Protected Forests has finished compiling a watershed classification with a scale of 1:250,000. Overall, the total watersheds in Indonesia are 17,076 watersheds with an area of 189,278,753 hectares. Fig. 1 shows the distribution of watersheds that have been studied using SWAT model. Of 178 published papers, most of location for SWAT modeling were found in Java.

3. SWAT applications in Indonesia

Proper watershed management is a common goal of the development of the SWAT model. Several researchers have contributed to conducting studies on the application of SWAT hydrological modeling in several watersheds in Indonesia. A paper reviewed methodological approach has been applied in this study to see how far the development of the SWAT model application in Indonesia. An overview of the method is illustrated in Fig. 2.

By December 2021, applications of SWAT model in Indonesia have been found in 178 publications based on

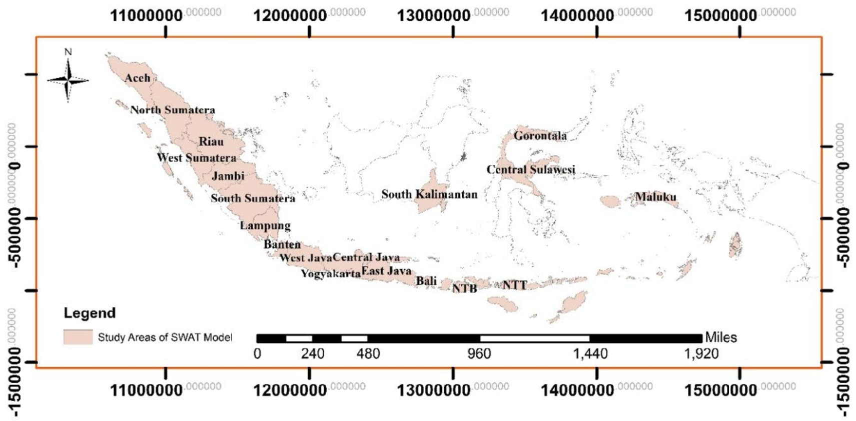

Fig. 1. Study areas of SWAT model application based on the provinces in Indonesia.

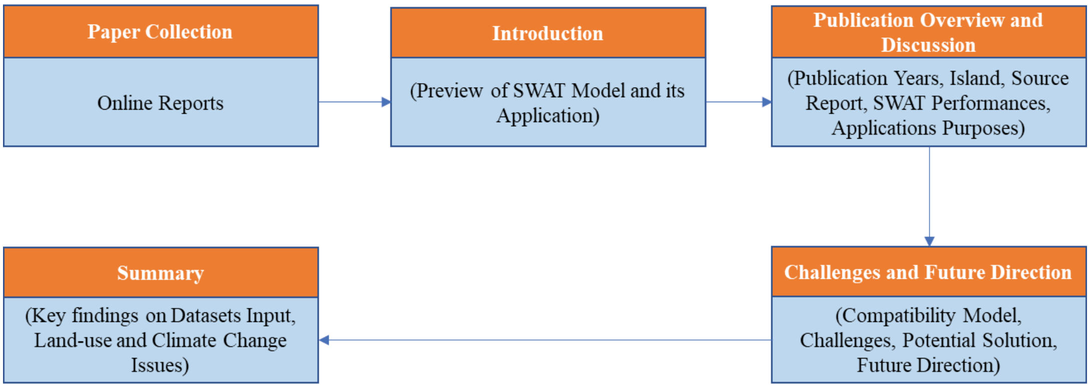

Fig. 2. Paper reviewed methodological approach.

the number of online scientific publications that have passed peer-review. Scientific articles, in both Indonesian and English-language, in national and internationals journals and conferences, were collected from December 2, 2021 to January 20, 2022. In collecting data, the application of the SWAT model was not limited to publications that were included in the international level, but also data which was taken from publications at the national level with the aim of seeing the whole effort in using the model.

The first SWAT application in Indonesia was carried out in the Lesti and Brantasi watersheds in 2007 [40,41]. The two locations for the application of this model were in East Java Province, where Lesti watershed is one of the upstream areas of the Brantas watershed. The purpose of these two applications was to assess runoff, sediment and nutrient parameters [40] whilst other publications aimed to survey and identify sediment and nutrient pollutant resources in Lesti watershed, as well as to assess the determination of the total maximum daily load of suspended sediment and nutrients as nitrogen and phosphorus [41]. No publication of the use of the SWAT model was found in 2008 and 2009 (Table 1). Afterward, reports on the uses of this model started again in 2010 and experienced a very drastic increase from 2017 to 2021. The report on the highest use of this hydrological model occurred in 2020 in as many as 33 publications (Table 2).

Based on the area, the area having the largest usage of this semi-distribution approach is Java Island, published in 112 publications. From 112 publications, the West Java Province had the most uses as many as 56 publications where three of them were applied in watersheds which intersect in two or more provinces, that is, Banten – West Java – Jakarta in the Ciliwung watershed [122], and West Java – Banten in Cidurian and Cisadane watersheds [178,211]. Citarum watershed (9 publications), Cidsane watershed (10 publications), and Ciliwung watershed (7 publications) are watersheds that have been designated as priority watersheds for ecosystem restoration. It is a promising indicator for watershed planning and management that the SWAT model is emerging in these areas.

The use of SWAT models in Indonesia varied greatly from very large watersheds to very small watersheds. According to the Regulation of the Director General of Watershed Management and Social Forestry [217], watersheds are classified into five size groups based on the total area of the watershed, that is, very large watershed (1,500,000 Ha and above), large watershed (500,000 ≤ 1,500,000 Ha), medium watershed (100,000 ≤ 500,000 Ha), small watershed (10,000 ≤ 100,000 Ha) and very small watershed (less than 10,000 Ha). With a total of 85 publications, the model is still most frequently applied in small size watershed (Fig. 3).

Table 1
Total of SWAT model applications in Indonesia (2007–2021)

Year of publication	Number of publications
2007	2
2008	0
2009	0
2010	3
2011	2
2012	6
2013	4
2014	10
2015	13
2016	9
2017	22
2018	19
2019	26
2020	33
2021	29
Total	178

Table 2
References of the SWAT studies

Island	Number of publications	References
Maluku	1	[42]
Kalimantan/Borneo	3	[43–45]
Nusa Tenggara	8	[46–53]
Sulawesi	18	[54–71]
Sumatra	36	[72–106]
Java	112	[40,41,107–216]

Meanwhile, the applications of the model in large watersheds were only found in two publications. Classification of the size of a watershed is very important as well, since the size of a watershed tends to affect the simulation of nitrogen and phosphorus parameters, although it has little effect on the simulation of river discharge [218].

During the process of calibration and validation model, the size of the watershed that was classified as large and very large, usually took time consuming for running the SWAT model and required higher computer specifications. From Fig. 3, it can be seen that 5 of 178 publications did not report the size of the watershed that was applied to SWAT.

4. SWAT performances in Indonesia

A hydrological model can be trusted or used to predict or simulate a hydrological process if the model has gone through a calibration and validation process. The calibration process is a process to provide an estimate of the value of the model parameters that minimizes the error between the predicted value and the data value from the measurements in the field [219]. At the same time, the validation process is the process of confirming the performance of the model outside the calibration process period without changing any parameters [220]. The SWAT model calibration process can be carried out in two ways, namely the manual method and the automatic method. Both techniques have their respective advantages. Automatic calibrations such as using SUFI-2 in the SWAT-CUP can speed up the calibration process. However, if the modeler calibrates manually, it can add knowledge about what parameter conditions are sensitive to the output and also add a sense of the range of parameter values [36].

The most frequently used quantitative statistics in Indonesia in assessing the performance of the SWAT model are the Nash–Sutcliffe efficiency (NSE) and the coefficient of determination (R^2). Table 3 summarizes the values of NSE and R^2 to present the performance of the SWAT model in Indonesia. Based on these results, an average of more than 50% of publications for the calibration and validation processes with quantitative statistics on both on daily and monthly scales was not reported or calculated. This condition is contrary since a model is sufficient to simulate or predict hydrological processes if performance of the quantitative statistics is considered feasible. Reporting model performance based on quantitative statistics was very diverse, ranging from reporting quantitative statistics values of daily or monthly calibration, daily calibration and validation, and monthly calibration and validation.

$$R^2 = \left[\frac{\sum_{i=1}^{n} \left(O_i - \bar{O}\right)\left(S_i - \bar{S}\right)}{\sqrt{\sum_{i=1}^{n} \left(O_i - \bar{O}\right)^2} \sqrt{\sum_{i=1}^{n} \left(S_i - \bar{S}\right)^2}} \right] 0 \leq R^2 \leq 1 \quad (2)$$

$$\text{NSE} = \frac{\sum_{i=1}^{n} \left(O_i - \bar{O}\right)^2 \sum_{i=1}^{n} \left(S_i - \bar{O}_i\right)^2}{\sum_{i=1}^{n} \left(O_i - \bar{O}\right)^2} \quad (3)$$

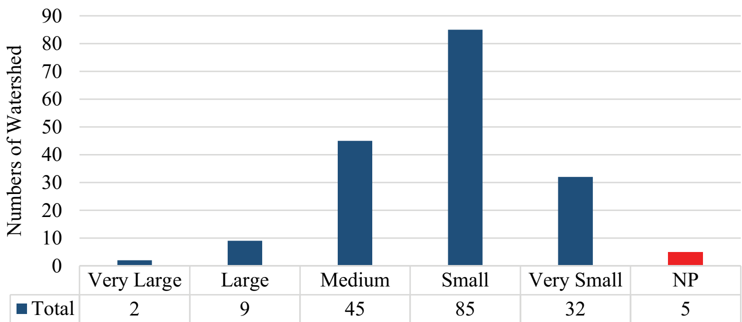

Fig. 3. Classification of SWAT application based on watershed sizes. *NP: Not reported.

Table 3
Performance rating of applied SWAT model in Indonesia

Performance rating [221]	Frequency ranges	Monthly				Daily			
		Calibration		Validation		Calibration		Validation	
		NSE	R^2	NSE	R^2	NSE	R^2	NSE	R^2
Very Good	0.75–1.00	14	27	4	1	7	18	4	7
Good	0.65–0.75	13	10	9	3	12	14	6	9
Satisfactory	0.50–0.65	13	7	7	8	22	15	12	14
Unsatisfactory	<0.50	7	1	5	14	11	4	12	2
Not reported or not calibrated		125	129	149	150	122	124	141	145
Multiple report and the others		6	4	4	2	4	3	3	1
Total		178	178	178	178	178	178	178	178

In general, the simulation model is considered satisfactory if NSE > 0.50 and RSR ≤ 0.70. Furthermore, PBIAS is ± 25% for stream flows, PBIAS ± 55% for sediments, and PBIAS ± 70% for N and P [221]. However, not all reports or publications performed sufficient information regarding quantitative statistics, hence not all SWAT report performances could be rated with the standards developed by Moriasi et al. [221]. Therefore, to ease the performance of SWAT model in Indonesia, a range or class was made from the NSE and R^2 values as the quantitative statistics that were most often used in Indonesia. Table 3 was made up of a range or class of NSE and R^2 values, which were less than 0.5 (class IV), 0.50–0.65 (Class III), 0.65–0.75 (Class II), and 0.75–1.00 (Class I). NSE and R^2 both have the same value range from 0 to 1.0. The higher those values, the better the performance of a hydrological model. From Table 3, the performance of the model in Indonesia was still evenly distributed in all classes. In fact, there were many publications that were in class IV, which means that the NSE and R^2 values were below 0.5 for both daily and monthly scale.

5. Performance based on watershed size

The comparison of the distribution of NSE and R^2 values between watershed sizes is illustrated by the boxplot in Figs. 4 and 5. To easily visualize the performance of the SWAT model that has been applied in Indonesia, the NSE and R^2 values generated during the calibration and validation stages are combined in one respective graph.

The median NSE for medium watersheds was the highest at monthly time step, but the medium-sized watershed had the least variety (Fig. 4a). Nevertheless, in each watershed size there are still extreme NSE values such as those in very small, small, and medium size watersheds. At the daily time step (Fig. 4b), the distribution is different, and the large watershed class has the highest median and the widest range of NSE values.

Fig. 5a shows that the R^2 value from the combination of the calibration and validation results tends to be relatively equal. There are no significant differences in the boxplot size on a monthly scale, but very small watersheds still have a very extreme R^2 value. In Fig. 5b the boxplot sizes for very small, small, and medium watersheds tend to be the same, indicating that the range of diversity of R^2 values in these watersheds tends to be equal. However, the median value of R^2 on a large watershed scale is lower than that of other watershed measures.

6. Digital Elevation Model

Digital Elevation Model (DEM) is one of the substantial input data in modeling the hydrological process using the SWAT model. DEM data quality can affect watershed delineation, river network and subwatershed classification (HRU) in the model [222]. The smaller the spatial resolution or better the quality of the DEM, the better the SWAT simulation output will have resulted. Thus, the availability of DEM data quality can determine the performance of a hydrological model. Based on research conducted by Zhang et al. [223], in highland watersheds, sensitivities of DEM resolution to monthly flow, sediment, dissolved oxygen, NH_4–N, NO_3–N, total nitrogen (TN) and total phosphorus

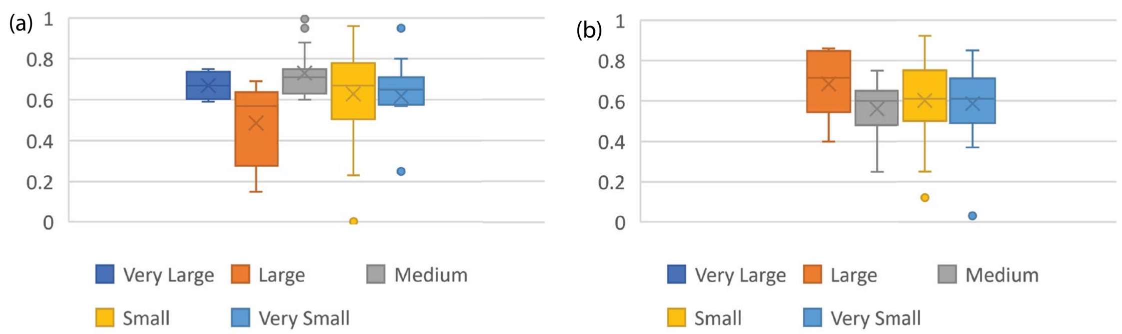

Fig. 4. NSE value of (a) monthly and (b) daily calibration and validation.

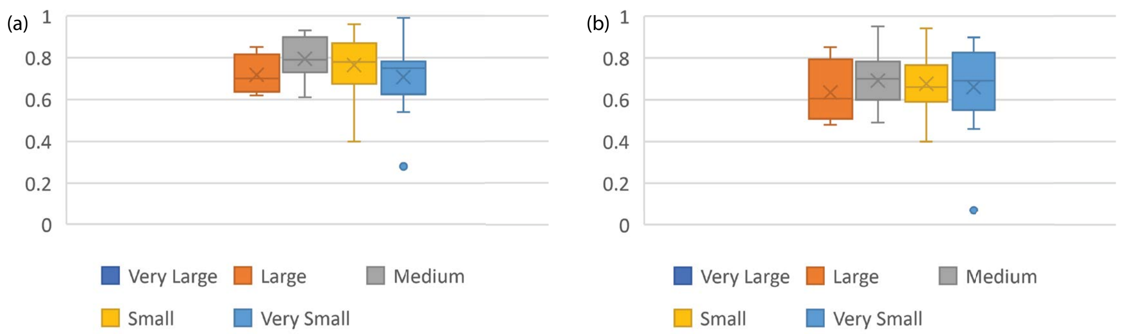

Fig. 5. R^2 value of (a) monthly and (b) daily calibration and validation.

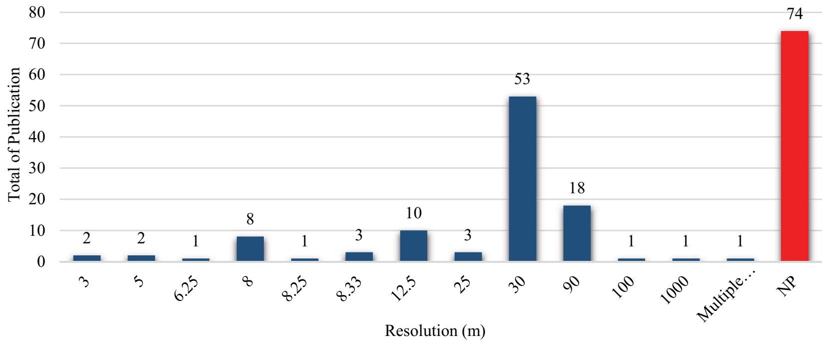

Fig. 6. Applied DEM resolution. *NP: Not reported.

(TP) were found, although the degree of sensitivity varied significantly.

From Fig. 6, many reports on the use of SWAT applications in Indonesia did not provide information regarding DEM resolution. From 178 publications, there were 74 publications that did not report the resolutions. The DEM resolution range that has been used in Indonesia ranged from 1,000 to 3 m. A 30 m DEM resolution was frequently used in the model which was found in 53 publications. The highest DEM resolution (3 m × 3 m) has been applied to model Kampar Kanan Sub watershed (Riau, West Sumatra) [105] and Kedurus watershed (East Java) [127]. Regarding the sensitivity test to DEM quality, in Indonesia researchers have started an effort to measure the sensitivity level to DEM resolution (50 and 25 m) [191]. However, the results have not discovered any sensitivity to the resolution of spatial data. In the publication, it was mentioned this was due to the soil data at the two map scales were not much different.

7. Purposes of SWAT application in Indonesia

This semi-distribution hydrological model has been used for several purposes in watershed management in Indonesia. In principle, the SWAT model can simulate water quality and quantity. Simulation of the water cycle on a watershed scale can assist in watershed management and solve various watershed problems such as flooding, drought, sediment, erosion, water quality pollution, etc. However, in Indonesia, the use of the SWAT model is relatively not diverse. The SWAT utilizations in Indonesia are classified into seven field studies (water quantity, land use impacts studies, erosion, climate impacts studies, sediment, climate and land use impacts studies, and water quality).

In Table 4, the purposes of the SWAT model application are still dominated in water quantity studies. There were 82 publications on water quantity studies with various specific purposes in an area. The water quantity studies have focused on analysis such as streamflow, runoff, groundwater, flood, drought, water balance analysis and so on. Studies on flood and drought hazard using this SWAT model have been found in seven and two publications, respectively. In addition to problem solving study, the application of the model for hydropower potential assessment was also found in five publications. The second frequent purposes are utilized for land use impacts studies in 50 publications.

Table 4
Uses of SWAT application in Indonesia

Main focus of study	Number
Water quantity	82
Land use impacts studies	50
Erosion	20
Climate change impacts studies	8
Sediment	8
Climate and land use impacts studies	5
Water quality	5
Total	178

Land use change studies using the SWAT model were also often combined with climate change studies with five publications. Meanwhile, there were eight publications focused on climate change studies.

The capability of this model was not only in simulating water quantity, but also in water quality. In Indonesia, researchers have also conducted water quality simulations in a watershed. Among those utilizations of SWAT, the water quality studies and combination of climate and land use impacts studies are still the lowest studies with five publications. The water quality studies were simulated including nitrite, nitrate, ammonium, phosphate, nitrogen, phosphorous, etc. In addition, studies on erosion and sediment analysis have also experienced an increase in the number of publications. As in Table 4, there were 20 publications on erosion simulations and eight publications carried out in sediment studies.

8. Challenges and future direction of SWAT application in Indonesia

Indonesia is referred to as an agrarian country because most of its population works in the agricultural sector and has extensive agricultural land and abundant natural resources. This state condition is certainly very suitable if the SWAT model is used in watershed management efforts. However, many studies have demonstrated the power of SWAT in simulating concentrations and loads of sediment, nutrients, climate change impacts on river flows, water yields, groundwater, and pollutant transport [9]. The SWAT model has demonstrated its ability to simulate water for use in future planning and management of agricultural-dominated areas [224].

The SWAT model application has been used in various conditions and is growing very rapidly. GIS greatly assists the development of input models through the GIS-model interface. The SWAT model and its GIS interface help in the study of water resources at the watershed scale and reduce the time and cost required to carry out such a study by a several-fold compared to other distributed parameter models [31]. However, limitations still exist when applied to several problems due to lack of data and the algorithm's incompatibility with problems in the field [225]. In addition, the challenges and limitations of the SWAT model are also on the daily time scale problem, uncertainty analysis of parameters, model updating problem, and low degree of data and model sharing, technical limitations of the existing model versions [10,226]. Another common challenge that is often faced in the use of the SWAT model is at the calibration stage of the SWAT model, especially the quality of rainfall and river discharge data [227]. Hence, the successful application of the SWAT hydrological model in areas where data is still scarce proves the potential for applying the model in data-limited watersheds [227].

Each field of studies has its own challenges in using the SWAT model as an analytical tool. Broadly speaking, field studies can be divided into two categories, namely water quantity studies and water quality studies. The challenge faced by both quality and quantity studies is the availability of observation data parameters in the field. In contrast to the availability of water quality data, water quantity data in Indonesia has increased and been published since 1909 [228]. The current condition of data availability is a major problem in the development of hydrological modeling.

The development of the SWAT model application in Indonesia has also been highly dependent on the availability of input data such as spatial data (DEM data, distribution of land use and soil types). Furthermore, the availability of climatological and hydrological time series data also greatly determines the performance of a hydrological model. For instance, the availability of high-resolution DEM data has still been very rare, hence most researchers only utilized data that has been easily accessible, that is, DEM with a resolution of 30 m (i.e., DEMNAS) provided by the Geospatial Agency of Indonesia. Data scarcity has become a severe challenge by users/modelers. The infrastructure for recording climatological and hydrological data in each watershed has not been evenly distributed and adequate. As such, this will be the main responsibility of the government to provide such infrastructures.

Heretofore, techniques of climatological and hydrological data generation have improved, one of which is using remote sensing techniques. Remote sensing techniques can provide great benefits for hydrology and water resources. Several case studies have been conducted that this technique has shown practical benefits [229]. Hydrological modeling in the watershed without monitoring data has been carried out in several places as conducted by Cotugno et al. [230], Jodar-Abellan et al. [231], and Boongaling et al. [232]. SWAT is promising and provides evidence for uses in areas where there is no observational data. It is concluded that the model results show good performance [233].

Remote sensing can provide a means to observe hydrological parameters over a wide area [234], therefore, this method is suitable for a very vast area of Indonesia. However, today, in Indonesia, the availability and uses of remotely sensed data is still lacking and rare. In fact, this is a great opportunity to replace traditional data sources (observed station) with remote sensing data. If those data are available, then the solution to the problem of water quality and quantity with the help of hydrological modeling is maximized.

In Indonesia, various watershed problems have emerged, both in quality and quantity. Therefore, government has also realized and mandated the restoration of several priority watersheds through the Strategic Plan (2015–2019) of the Ministry of Environment and Forestry. With this mandate, Indonesian researchers and other stakeholders can commence further observing the development of SWAT models in these priority watersheds so that the benefits of the SWAT applications can be more applicable.

In general, the use of the SWAT model in Indonesia has still been centered on the watersheds on Java Island. The island of Maluku and Kalimantan has still been significantly less use of the SWAT model. Even in Papua, hydrological modeling application has never been used in watershed management establishment. Furthermore, currently, the Indonesian government has planned to move the Indonesian capital to East Kalimantan Province, where moving the capital city to Kalimantan Island will certainly result in land conversion and will disrupt the ecosystem if the watershed management is not planned properly. Regarding such concerns, so far, the use of the SWAT model on Kalimantan Island has only been found in Batang Alai Sub Watershed (South Kalimantan) [43], Bua watershed (West Kalimantan) [44], and Sungai Besar watershed (South Kalimantan) [45]. In the future, the application of SWAT model in East Kalimantan and its surroundings will be an engaging region for various study needs regarding potential problems of the watersheds and water resources.

In addition, Papua Island is also a new prospective target for the use of SWAT model application, due to the occurrences of large watersheds or large rivers within the island. As mentioned, some of the rivers are even considered the 10 largest watersheds in Indonesia, such as Eilanden River (674 km), Mamberamo River (670 km), and Digul River (525 km). To avoid potential damages to watersheds in Papua, watershed management requires simulation to find the most appropriate and adaptive solution to the environment in the watershed.

The trend of SWAT model application has increased dramatically in recent years, the primary application of the model is still on the water quantity. Although the issue of climate change has become a rising concern in Indonesia, land use change studies were conducted in a higher number than climate change studies. In the future, the number of studies on climate change using SWAT model will potentially increase as the impacts of climate change in Indonesia become more evident. Combination studies between land use and climate change are often carried out in various regions of the world, where Indonesia has also experienced such a combination studies in several places from the provinces of Aceh [72], Jambi [87], East Java [235], Central Java [193], and Maluku [42].

Changes in land use and climate have various damaging impacts on watersheds such as floods, droughts, sediments, erosion and so on. The ability of the SWAT model in simulating hydrological processes both in quality and quantity will be the preferred choice of hydrological models in resolving these various impacts. The expansion of the study area using this model will increase as hydrological problems in the watershed become more complex. The increasing application of the model will provide a basic reference in developing this model, making it easier to build and extend SWAT model. This condition will encourage researchers to conduct research at a more advanced level. Furthermore, the integration of the SWAT model with land change models such as the Land Change Modeler (TerrSet, Mollusce) and climate change models such as General Circulation Models (GCM) to obtain land and climate change projections for the future years and their impact on the sustainability of the watershed.

Suppose the performance of the SWAT model in Indonesia increases, in that case, the opportunity to couple SWAT with other models will be more open, such as coupling with river models, groundwater models, flood models and others (MIKE11, HEC-RAS, MIKE FLOOD, etc.) to obtain better simulation results. As such, the SWAT model has the advantage of interfacing with other applications. This convenience will encourage researchers to experiment further to find the best watershed management practices.

9. Summary

The SWAT model has become a significantly frequent hydrological model utilization since 2017 in Indonesia. The uses have been carried out from 2007 to 2021 and have reached 178 publications, both in Indonesian and English. The uses of the SWAT model in simulating hydrological processes have still been dominant on Java Island. The biggest challenge faced by SWAT users in Indonesia is the poor quality of the available input data. If this challenge is successfully overcome, the purposes of SWAT models to conduct various types of analytical studies will increase and expectantly not only focusing on water quantity studies but also on other studies (e.g., erosion, climate impacts studies, sediment, water quality, etc.).

Conflict-of-interest statement

The authors declare that they have no conflict of interest.

Author contributions

MFI (Lecturer and Researcher) collected data and wrote the manuscript. MIR (Researcher), SN (Lecturer and Researcher), WP (Lecturer and Researcher), SFZ (Researcher), TF (Lecturer and Researcher) completed the manuscript.

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