Transport Modelling In Jakarta Groundwater Basin using QSWATMOD

G U Nugraha1*, I Ridwansyah2, D Marganingrum1, P Hartanto1, R F Lubis1, H Bakti1

1 Research Center for Geotechnology, Indonesian Institute of Sciences, Indonesia
2 Research Center for Limnology, Indonesian Institute of Sciences, Indonesia

*Corresponding author: g.utamas.n@gmail.com

Abstract. The Jakarta groundwater basin is constructed by tertiary, Pleistocene and recent rock consisting of sedimentary rocks, volcanic activities and alluvial. There are three very potential aquifer layers found in this basin i.e. shallow aquifers, upper confined aquifers, and lower confined aquifers bounded by several aquitard. High economic and development activities cause high vulnerability to polluted aquifers such as nutrients. Previous research mentioned the presence of nutrients in groundwater in urban areas can be caused by high anthropogenic activity. Nutrient contamination in groundwater can be a threat to ecosystems in coastal areas. The purpose of this paper is to understand nutrient transport patterns through groundwater hydrogeology systems in the Jakarta groundwater basin, so that the amount of groundwater contribution to the nutrient flux in the Jakarta bay can be estimated. To get the transport nutrient model, QSWATMOD tools in QGIS Software were used. The parameters used in transport nutrient modeling are the definition of subbasins in the SWAT hydrology model, Hydrological Response Unit (HRU), rivers, aquifer thickness, hydraulic conductivity, specific storage, specific yield, hydraulic head, porosity, longitudinal dispersivity, and denitrification rate constant. The sub-basins and river constraints used are the Ciliwung Watersheds fill the Jakarta groundwater basin. The result show Leached Nitrate at the study area was 42 kg/ha and total P loss were 5 kg/ha. However the higher groundwater recharge in the study area increased the risk of groundwater contaminant by nitrate.

1. Introduction
Coastal area is an area of interaction between land and sea. As zones of transition land and sea, the area of coast form a diverse ecosystem that is highly productive and provides economic value that is beyond the ordinary to the human and instrumental maintain ecosystems sea [1–4]. It is proved that the region of the coast into the area which is quite important and ideally that should be kept with a good sustainability. coastal area often receive large scale of activities of agriculture, mining, aquaculture fish, the waste industry and waste domestic which is connected with the river, which later led to the accumulation of materials of organic and inorganic as well as nutrients [3,5].

Increased nutrients in waters have positive impact by supporting the production of photosynthesis by phytoplankton which are directly going to increase the source power fishery. However at the level of specific, excess nutrients will have an impact on the reduction of oxygen dissolved in the water that triggers the growth of algae that is dangerous[6,7]. The growth of algae that is excessive is often referred to as eutrophication[5]. Eutrophication events can increase the number of dangerous red algae and can affect the composition of phytoplankton and have a negative impact on local fisheries[6,8].
The main types of nutrients that need to be controlled so as not to cause eutrophication are nitrate (N) and phosphate (P) [9][10]. Nutrients N and P have a role major in the growth of phytoplankton which is used for the chemical indicator in assessing the level of water fertility [6,11,12]. Nutrients are also needed by marine organisms in metabolism, physiological processes, and biochemical reactions and to control phytoplankton growth and metabolism [13]. Abundance and concentration of phytoplankton is influenced by physico-chemical factors [14] and the availability of nutrients which is a factor limiting the production of phytoplankton in the water [8,15].

Phosphate comes from rocks and sediments that enter the river and groundwater in the form of phosphate ions (PO4). In general, phosphate content in public waters is not more than 0.1 ppm. When the content of phosphate beyond the purposes of phosphates for growth normal of plant water will be the enrichment/eutrophication [15].

The excess concentration of nutrients trigger the uncontrolled growth of algae which lower the levels of oxygen. This condition has an impact on the growth of dangerous algae (Harmful Algal Bloom/HAB). When this HAB into the issue of global because it threatens the sustainability of the ecosystem of the waters, both aquatic freshwater or water sea. Even the alleged conditions change climate exacerbate the situation HAB which impact on the decline in the production of food of aquatic, sectors of tourism, provision of water to drink and trigger a decline in the economy of a region [16]. Various studies have been done to see the spread of N and P that cause the occurrence of eutrophication and HAB in the waters of the beach [6]. But there are not many studies that are preventive or mitigating excessive concentrations of N and P nutrient in water. Nutrients N and P were brought to the area of coastal beach with various mechanisms of one of them using the mechanism of the flow of groundwater, where the nutrients N and P entered into the ground towards to the zone of saturated water (aquifer). At least there are two kinds of aquifer, confined and unconfined aquifers. Confined aquifers are formed due to the presence of two confining layers (impermeable layers) at the top and bottom of permeable rocks (aquifers). Unconfined Aquifers are aquifers that do not have a layer of confining (impermeable layer in parts it ). Unconfined aquifer is an aquifer that has the worst impact of the spread of nitrate and phosphorus contamination to groundwater. Case is due to the unconfined aquifer does not have a part layer hood on top of it (cap) so that the water surface (rain) which is contaminated with nitrates and phosphorus can flow in a vertical or horizontal to layer it. Contamination of nitrates in the aquifer this can occur in the region of dense population and territory agriculture plantation. Needed a model of transport of nutrients through the groundwater toward the bay of Jakarta.

Figure 1. Schematic spread of contaminants nitrates in the aquifer is not depressed [6]
2. Material and Methods

2.1. Soil Water Assessment Tool (SWAT) Modeling

Soil Water Assessment Tool (SWAT) is a model of hydrologic scale of Watershed-based physical, deterministic, and continuous, which was developed by the USDA Agricultural Research Service[17,18]. SWAT Model was developed from a number of models of individuals in a period of more than 30 years and has been applied and tested in a variety of regions, character shape, scale of time, practice management of land in a span of time that is sufficiently wide[19]. SWAT uses climate data and spatial data distributed on topography, soil, land cover, land management, to estimate water yield, transported sediment, pesticide waste and others[20].

In operation, SWAT models can do some simulations on them practice management on land and in the channel of the river. Some simulations among other changes in land-use land, practice conservation of soil and water, and the presence of pound (building control sediment transported). The hydrologic cycle, the process that is taken into account in the SWAT model that takes place in the Watershed is based on the water balance.

![Figure 2](image-url)

**Figure 2.** Overview of the hydrological cycle in the SWAT model[19]

output model of SWAT is the condition of hydrology in the form of the value of the discharge, erosion, and sediment transported. The data needed in hydrological modeling using SWAT are:

1. Data precipitation
2. The SRTM 30 DEM map is obtained from the USGS website.
3. Watershed land use map
4. Map of the slope of the slope of Watershed
5. Map of Watershed soil types
6. Climatology data from the Global Weather Database.
2.1.1. Tools. The tool used to carry out the operation of the SWAT model is a set of laptops equipped with Arc GIS 10.4.1 software that has been equipped with the ArcSWAT 2012 extension.

2.1.2. Modeling Stages. Model hydrology were selected in the study of this form of SWAT. Stages of analysis of data delineation Watershed and the establishment of HRUs (Hydrologic Response Units), analysis of rain data, the analysis of discharge flow of the river, the analysis of the calibration-validation. SWAT Hydrological model with System Information Geographic (GIS) software-based as an extension plug-in of ArcGIS 10.2, while the pace of work that must be done includes the stages as follows:

1. Database models of hydrological SWAT, preparatory stage of the work that the first is a database, includes: climatology data (precipitation, rainfall, temperature, sun radiation, wind-speed and relative humidity) in the form of files (.txt) or text delimited or (. Dbf ) ESRI dbase files, Data of land use/land cover and the data of soil types in the form of ( shp ) or ESRI shape file or ESRI Grid, the data DEM (Digital Elevation Model) in the form of ESRI Grid.
2. Making the boundary Watershed (Watershed delineation), the stage is among others done, DEM Setup, defines stream (Stream), Outlet and Inlet.
3. Overlay on the type of land use, soil type, and Watershed boundaries, at this stage there are several processes, namely:
   a. Determining the type of governance in order to land, made the process of overlapping of data governance in order to land (use maps in order to land ) to the result of making the boundary of the Watershed. Determination of the classification system in order to land based on the determination of the type of governance in order to land crop and urban.
   b. Determination of soil type, the process of overlapping data on soil types (map of soil types ) against Watershed boundaries is carried out. Furthermore, do determine the classification of the type of soil based on the determination of the standard USDA.
   c. Slope class classification, based on DEM data, is divided into five classes, namely 0-8%, 8-15%, 15-25%, 25-40%, and> 40%.
   d. Overlay maps of land use, soil types, and slopes. The overlay process is used to determine the spatial distribution of these parameters for the analysis of the HRU (Hydrologic Response Unit).
4. HRU Distribution Determination, at this stage, is done by two methods, namely dominant landuse and soil or multiple hydrologic response units. If you choose a model of multiple HRU needs to be done determining the limits of the size of the minimum (threshold) for the system to land and the type of soil.
5. Import Data Weather (Weather Stations), the stage is carried out data import from the weather, namely precipitation of rain, temperature, radiation sun, and humidity relative. This measurement data is entered into the processing of ArcSWAT software which is optional, which can be adjusted to the user's wishes (custom database). The type of data used is daily data.
6. Input Data, the stage is processing the data of climate and weather, HRU of data, water data ground (groundwater), the data channel is the main.
7. Edit ArcSWAT input Data, at this stage data editing is done, namely watershed parameters that can be improved data before doing the ArcSWAT simulation process. Some data that can be improved, namely: Point source input, Inlet discharges, Reservoirs, Sub basins, Soil parameters, input data: Weather generator, General sub basin, General HRU, Edit main channel, Edit groundwater, Edit water use, Edit management, Edit soil chemical, Edit pond or wetland, Edit stream quality.
8. The reading of the input parameters (input Watershed rewriting files), do reading the parameters required. User software ArcSWAT can choose the data that will be required for the simulation ArcSWAT.
9. Simulation ArcSWAT (running process):
   a. The period of simulation, set the date of the beginning and end of the simulation.
   b. Rainfall, runoff, or routing, set selection is used precipitation time step, run-off calculation method, and routing time step.
   c. Rainfall distribution, have distributions that are used to generate the data of rain.
   d. Potential ET method, selected methods are used to determine evapotranspiration potential (PET).
   e. Water channel routing method, have a method that is used to route the water in the tissue tract Watershed.
   f. Channel dimension, illustrates there or whether dimension channels were allowed to change over the state of the simulation in connection with channel degradation.
   g. Print out frequency, control the frequency of available data output, i.e. daily, monthly, and yearly.

10. ArcSWAT simulation (running process), at this stage can set several stages of the running process, namely:
   a. Sub-basin output file (.bsb), lists of information that exist in each subzone or summary of the HRU in each subzone.
   b. Main channel output file (.rch), contains a summary of information on the contents of the incoming Watershed and channel outputs.
   c. HRU output file (.sbs), contains summary of HRU WATERSHED information.

2.2. SWAT-MODFLOW
SWAT-MODFLOW is an integrated hydrological model that combines SWAT's ground surface processes with spatially explicit groundwater flow processes [17]. QSWATMOD is a QGIS-based graphical user interface that facilitates connecting SWAT and MODFLOW, running SWAT-MODFLOW simulations, and viewing results.

The data needed in hydrological modeling using SWAT-MODFLOW are:
1. The DEM SRTM 30 map is obtained from the USGS website.
2. Aquifer Thickness
3. Hydraulic Conductivity
4. Specific Storage
5. Specific Yield
6. Initial Hydraulic Head (groundwater level)

2.3. Model Development Stage
The integration of the SWAT-Modflow model is an attempt to model the interaction of groundwater with surface water. This research has been carried out by several researchers such as [17,21–23]. The official SWAT page has provided the stages of building the SWAT-Modflow model, model examples and executable files.

The SWAT input file used is the entire contents of the txtinout folder. In MODFLOW, file input that is needed is the result of the construction of the model MODFLOW-NWT with modules river, recharge, and upstream weighting package. Data link between the two models that need to be prepared is a liaison HRU with disaggregated HRU (DHRU), connecting DHRU-grid cell MODFLOW are sorted by number DHRU smallest and sorted by the number of grid cell the smallest, as well as connecting the river to the grid cell MODFLOW. DHRU is obtained by multipart to singlepart tool in ArcMap against HRU. Merging each data is done with the intersect tool in ArcMap to then retrieve the required data and then arrange it according to the given format. The entire file and then placed in a folder at the following also with SWAT-Modflow.exe to run the command prompt.
3. Result and Discussion

3.1. SWAT
The Ciliwung Watershed land cover is mostly Residential Medium to low density with a percentage of 56.81%. Soil types in the Ciliwung Watershed based on the Soil Map World (DSMW) soil map from FAO are dominated by Okrik andosol associated soil types. The slope class classification in the Ciliwung River Basin is carried out using a 30 m DEM resolution. The slope classes in the Ciliwung Watershed are spread throughout the entire kerengan class. Ciliwung Watershed is dominated by slope class of 0% -8% with a percentage of area of 52.60% which is included in the slope class.

3.2. HRU

Figure 3. Hydrological Response Unit
The results of the analysis show that the annual rainfall is 3083 mm / year. The value of evaporation and transpiration at the study area was 1043 mm / year. Evapotranspiration potential of...
1487 mm/year. The surface runoff has a value of 793 mm/year. The average curve number at the research location is at the value 76.33. The amount of recharge to the unconfined aquifer zone is 1000 mm/year, and recharge to the confined aquifer is 50 mm/year. Revap from the shallow aquifer of 28 mm/year. Lateral flow is 239 mm/year, and returns flow is 920 mm/year.

The results show that the Total N Loss in the model is 75 kg/ha. The total organic N is 21 kg/ha. Nitrate Surface Runoff at the study area was 8 kg/ha. Leached Nitrate at the study area was 42 kg/ha. Lateral flow nitrate of 2 kg/ha. Groundwater Yield Nitrate of 1.5 kg/ha. Total P loss were 5 kg/ha. Organic P in the study area were 5 kg/ha. Soluble P Surface runoff were 0.6 kg/ha. Solubility ratio in runoff was 0.1 kg/ha.

3.3. SWAT-MODFLOW

Annual discharge rate were 5 – 58 m3/year in the study area (Figure 6). However this data need to be validated by the actual discharge rate on the stream gauge. Stream discharge value might be impacted by high groundwater contribution to this stream channel. Figure 7 show the water balance model in the study area. However, the large amount of groundwater recharge in the study area can impact the risk of Nitrate leached in the study area. This contaminated groundwater can flow into river or the bay of Jakarta.
4. Conclusion
Water balance analysis results show annual rainfall of 3083 mm/year, surface runoff 793.21 mm/year, lateral soil 238 mm/year, recharge to shallow groundwater 919.83 mm/year, recharge to deep groundwater 49.18 mm/year, potential evapotranspiration 1487 mm/year. Leached Nitrate at the study area was 42 kg/ha. Total P loss were 5 kg/ha.

Author Contributions
Gumilar Utamas Nugraha is a main Contributor and others as support. Iwan Ridwansyah were charge of evaluation of SWAT modelling. Dyah Marganingrum and Rachmat Fajar Lubis were in charge of the manuscript writing. Priyo Hartanto and Hendra Bakti was in charge of the overall manuscript structure and took part in the fieldwork.
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References

[1] Kelbe B E, Taylor R H and Haldorsen S 2011 Groundwater hydrology Ecology and Conservation of Estuarine Ecosystems: Lake St Lucia as a Global Model
[2] Nobre A M 2009 An Ecological and economic assessment methodology for coastal ecosystem management Environ. Manage.
[3] Jin D, Hoagland P and Dalton T M 2003 Linking economic and ecological models for a marine ecosystem Ecol. Econ.
[4] Byron C J, Jin D and Dalton T M 2015 An Integrated ecological-economic modeling framework for the sustainable management of oyster farming Aquaculture
[5] Smith V H 2003 Eutrophication of freshwater and coastal marine ecosystems: A global problem Environ. Sci. Pollut. Res.
[6] Heisler J, Glibert P M, Burkholder J M, Anderson D M, Cochlan W, Dennison W C, Dortch Q, Gobler C J, Heil C A, Humphries E, Lewitus A, Magnien R, Marshall H G, Sellner K, Stockwell D A, Stoecker D K and Suddleson M 2008 Eutrophication and harmful algal blooms: A scientific consensus Harmful Algae
[7] Pae rl H W, Gardner W S, Havens K E, Joyner A R, McCarthy M J, Newell S E, Qin B and Scott J T 2016 Mitigating cyanobacterial harmful algal blooms in aquatic ecosystems impacted by climate change and anthropogenic nutrients Harmful Algae
[8] Anderson D M, Burkholder J M, Cochlan W P, Glibert P M, Gobler C J, Heil C A, Kudela R M, Parsons M L, Rensel J E J, Townsend D W, Trainer V L and Vargo G A 2008 Harmful algal blooms and eutrophication: Examining linkages from selected coastal regions of the United States Harmful Algae
[9] Howarth R W 2008 Coastal nitrogen pollution: A review of sources and trends globally and regionally Harmful Algae
[10] Granéli E, Weberg M and Salomon P S 2008 Harmful algal blooms of allelopathic microalgal species: The role of eutrophication Harmful Algae
[11] Dortch Q 1990 The interaction between ammonium and nitrate uptake in phytoplankton Mar. Ecol. Prog. Ser.
[12] Yool A, Martin A P, Fernández C and Clark D R 2007 The significance of nitrification for oceanic new production Nature
[13] Tyrrell T 1999 The relative influences of nitrogen and phosphorus on oceanic primary production Nature
[14] Sharma R C, Singh N and Chauhan A 2016 The influence of physico-chemical parameters on phytoplankton distribution in a head water stream of Garhwal Himalayas: A case study Egypt. J. Aquat. Res.
[15] Anderson D M, Glibert P M and Burkholder J M 2002 Harmful algal blooms and eutrophication: Nutrient sources, composition, and consequences Estuaries
[16] Ho J C and Michalak A M 2015 Challenges in tracking harmful algal blooms: A synthesis of evidence from Lake Erie J. Great Lakes Res.
[17] Kim N W and Arnold J G 2008 Development and application of the integrated SWAT – MODFLOW model 1–16
[18] Neitsch S., Arnold J., Kiniry J. and Williams J. 2011 Soil & Water Assessment Tool Theoretical Documentation Version 2009 Texas Water Resour. Inst.
[19] Park S, Nielsen A, Bailey R T, Trolle D and Bieger K 2019 Environmental Modelling & Software A QGIS-based graphical user interface for application and evaluation of SWAT-MODFLOW models Environ. Model. Softw. 111 493–7
[20] Srinivasan R 2005 ArcSWAT: ArcGIS interface for soil and water assessment tool (SWAT) Temple, Texas Texas A&M Univ.
[21] Wei X, Bailey R T, Records R M, Wible T C and Arabi M 2019 Environmental Modelling & Software Comprehensive simulation of nitrate transport in coupled surface-subsurface hydrologic systems using the linked SWAT-MODFLOW-RT3D model Environ. Model. Softw. 122 104242
[22] Liu W, Bailey R T, Estrup H, Jeppesen E, Park S, Thodsen H, Nielsen A, Molina-navarro E and Trolle D 2020 Science of the Total Environment Assessing the impacts of groundwater abstractions on flow regime and stream biota: Combining SWAT-MODFLOW with flow-biota empirical models Sci. Total Environ. 706 135702
[23] Mosase E, Ahiablame L, Park S and Bailey R 2019 Modelling potential groundwater recharge in the Limpopo River Basin with SWAT-MODFLOW Groundw. Sustain. Dev. 9 100260