# *Analysis method and result of water resources potential on surface water*

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**JICA Project Team**

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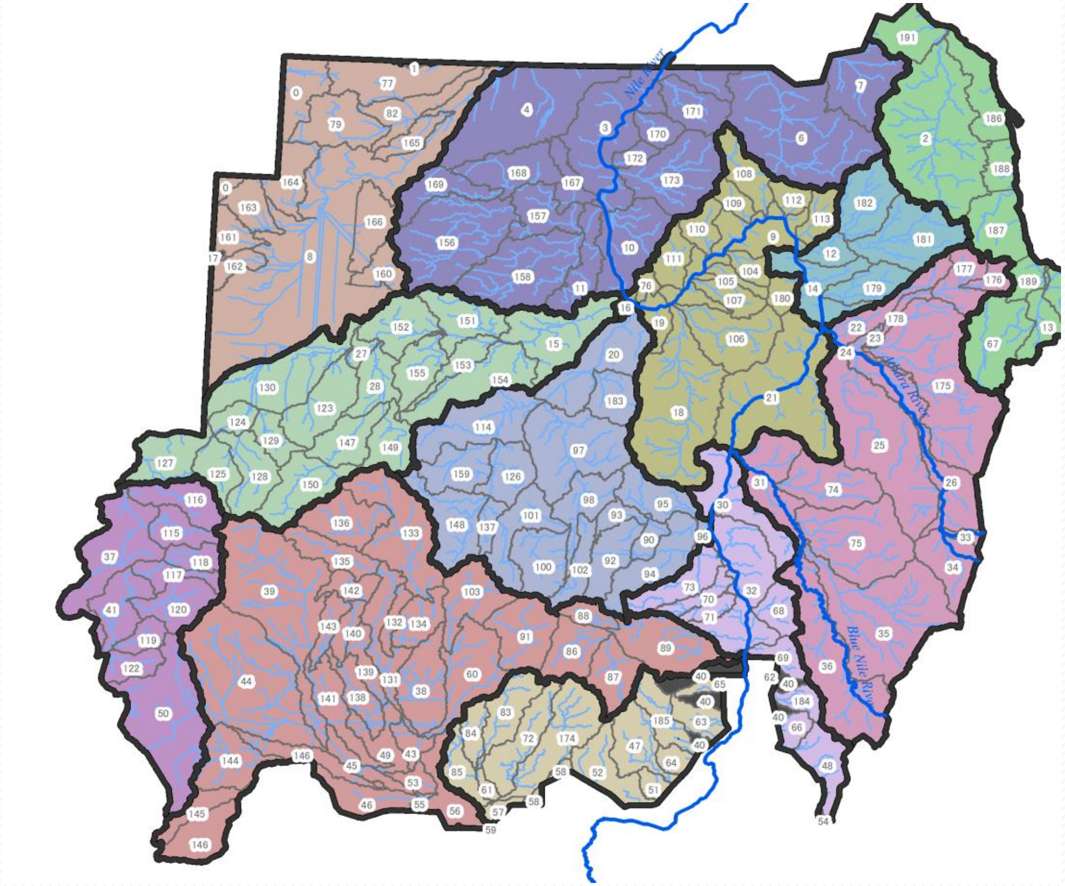
**RECS INTERNATIONAL INC.**

# ***Water balance analysis of Non-Nile Catchment delineation***

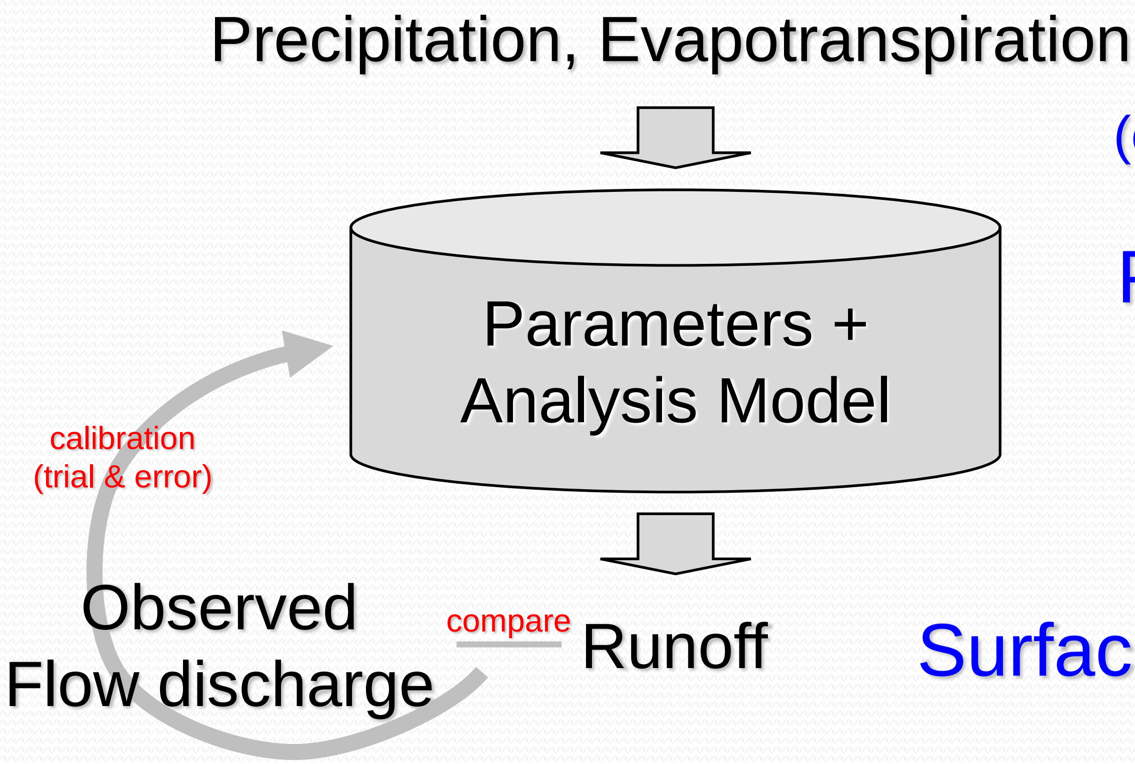



**- 12 Basins**
**- 191 sub-basins**

| Basin No. | Basin Area (km2) | Number of sub-basin included |
|---|---|---|
| 1 | 164,809 | 12 |
| 2 | 252,981 | 16 |
| 3 | 109,502 | 9 |
| 4 | 51,877 | 5 |
| 5 | 154,047 | 17 |
| 6 | 231,983 | 15 |
| 7 | 167,209 | 18 |
| 8 | 166,851 | 18 |
| 9 | 96,469 | 10 |
| 10 | 310,123 | 32 |
| 11 | 88,998 | 15 |
| 12 | 75,708 | 10 |
| Total | 1,870,558 | 177 |

This sub-basin delineation is proposed to be used for water resources management in Non-Nile Area for the future

# Long-term Rainfall-Runoff Analysis




Input
(observed data)
×
Parameters
×
Model

Surface Water Potential

3 elements are all essential.

Calculation result will not be appropriate without the appropriate input data, even if the model is sophisticated.

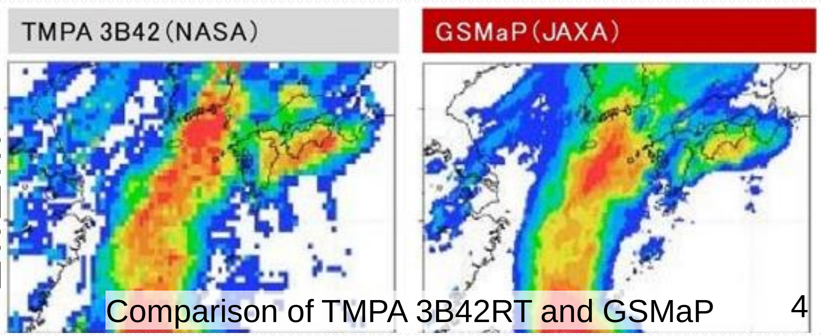
# Input Data (Precipitation)

- Available observed data by Sudan Metrological Authority is very limited (around 30 stations in the whole Sudan)
- Other observed data (such as the data of Ministry of Agriculture) will take time to collect and organize the data for input data within the limited time
- On the other hand, <u>several global satellite observation data in high resolution are available freely</u> (such as GSMaP by Jaxa, TMPA 3B42RT by NASA and so on)

| Data | GSMaP *[1] | Observed data in Sudan | TMPA 3B42RT* |
|---|---|---|---|
| Data source / Organization | JAXA (Japan Aerospace Exploration Agency) | Sudan Meteorological Authority | NASA (National Aeronautics and Space Administration) |
| Year of observation | Mar. 2000 ~ Feb. 2014 | Depends on the station (Before 1950 ~) | Mar. 2000 ~ |
| Spatial Resolution | Approx. 10 km | 26 observation stations | Approx. 25 km |
| Time interval | Every 1 hr, Daily | Daily | Every 3 hrs |
| Cost | Free | 100,000 SDG (for 30 years) | Free |

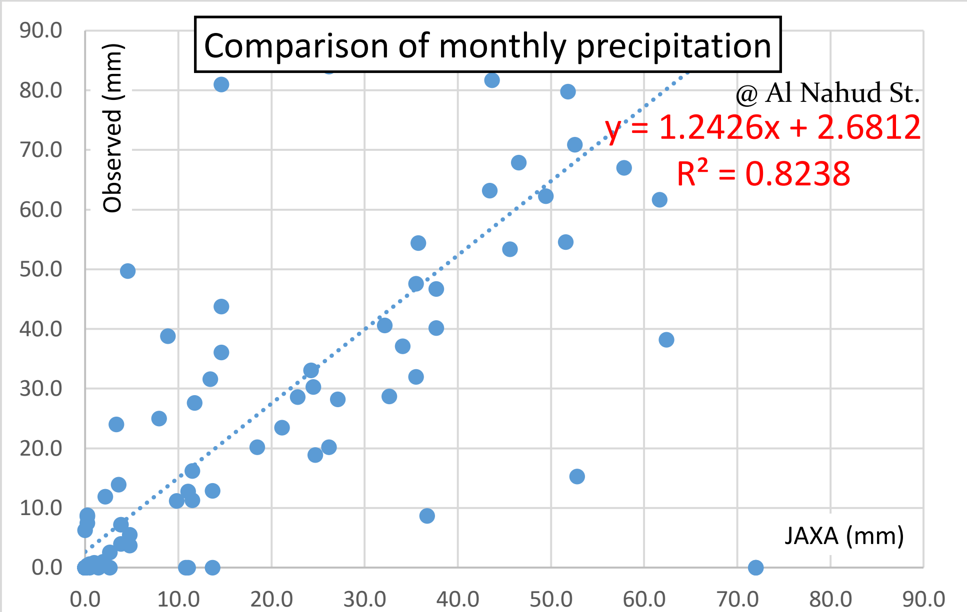
[1] GSMaP (http://sharaku.eorc.jaxa.jp/GSMaP/index_j.htm)
* source: Annual business report in 2014, JAXA
***Red***: *Advantage*, ***Blue***: *Disadvantage*, □: *Data to be used*

✓ Therefore, ***<u>GSMaP and observed data</u>*** in Sudan were used in the Project



Comparison of TMPA 3B42RT and GSMaP

# Input Data (Precipitation)

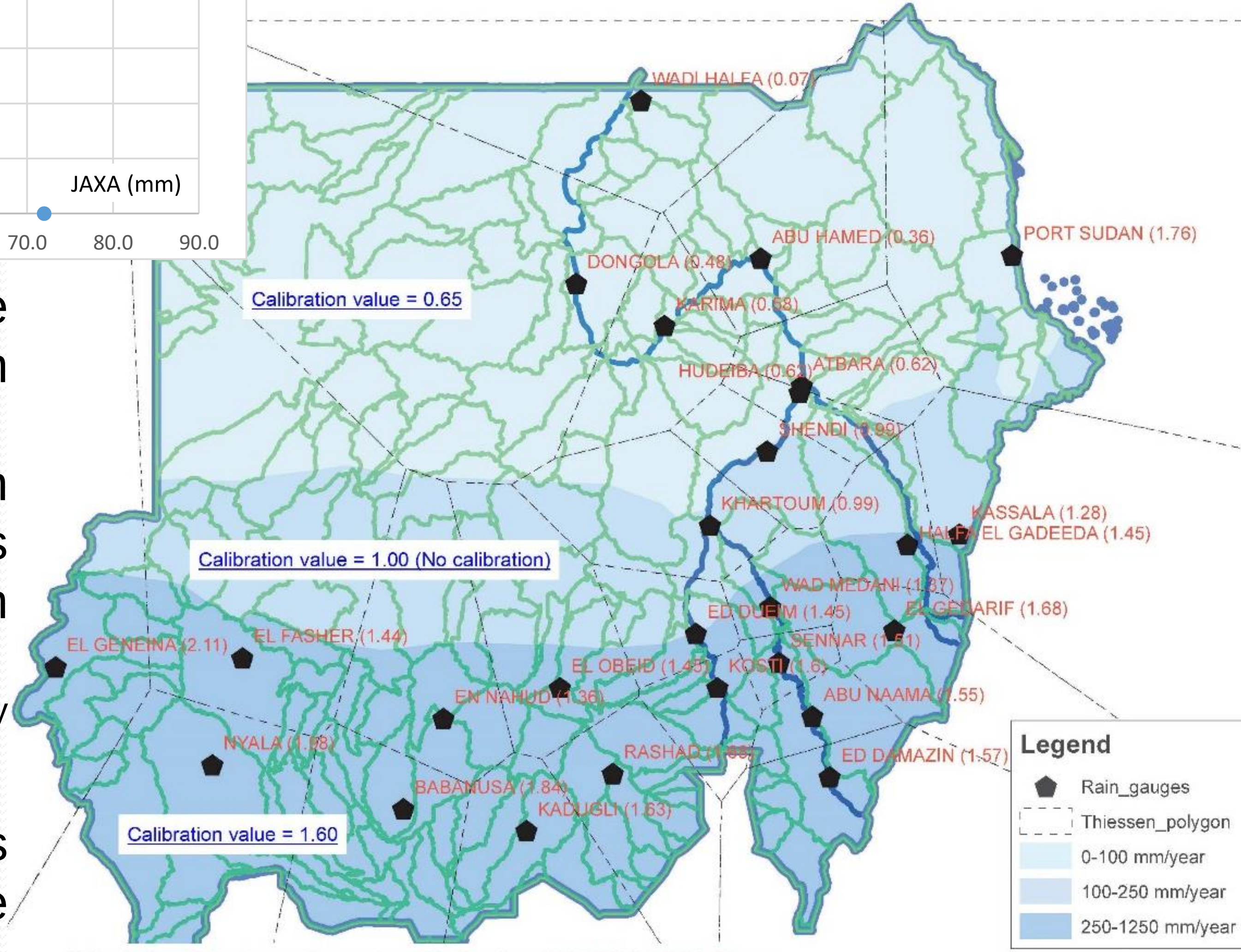



- Precipitation of the GSMaP is different from the observed data

→ Average correlation coefficient of 18 stations in the south of Khartoum = 0.69

(*There is very weak correlation in the dry area in the north of Khartoum)

- The GSMaP data was calibrated comparing the observed data




Value in () = SMA observed annual precipitation from 2000-2013 / GSMaP's one
Average value = calibration value in each area

Boundary representation is not necessarily authoritative
Source of isohyetal line: World Trade Press 2012

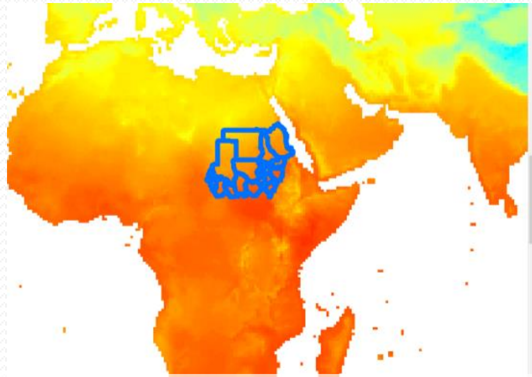
# Input Data (Temperature for PET)

- Similar situation as precipitation
- Several global satellite observation data in high resolution are available freely (such as CRU-TS3.1 by BADC, Worldclim by MBZ and so on)

| Data | CRU-TS [1] | Observed data in Sudan | Worldclim [2] |
|---|---|---|---|
| Data source / Organization | BADC (British Atmospheric Data Center) | Sudan Meteorological Authority | Museum of Vertebrate Zoology, University of California |
| Year of observation | 1901 ~ | Depends on the station (Before 1950 ~) | Gridded long-term averaged (1960 ~ 1990) |
| Spatial Resolution | Approx. 50 km | 26 observation stations | Approx. 1 km |
| Time interval | Monthly | Daily | Only 12 monthly data @ each point **(30-year averaged data)** |
| Cost | Free | 100,000 SDG (for 30 years) | Free |

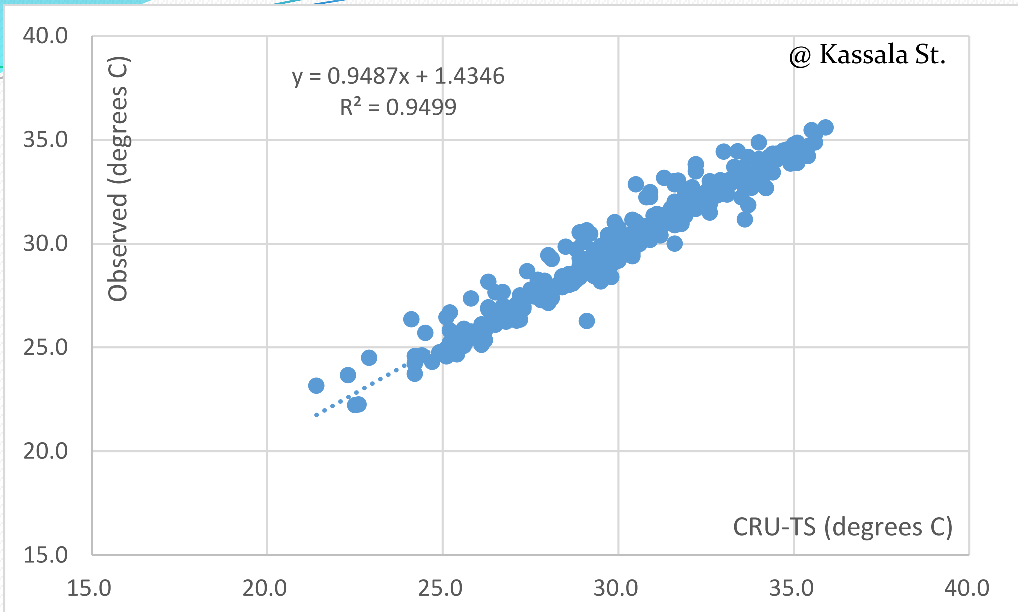
[1] CRU-TS3.1 (https://climatedataguide.ucar.edu/climate-data)
[2] Worldclim (http://www.worldclim.org/version1)
***Red***: *Advantage*, ***Blue***: *Disadvantage*, ☐: *Data to be used*

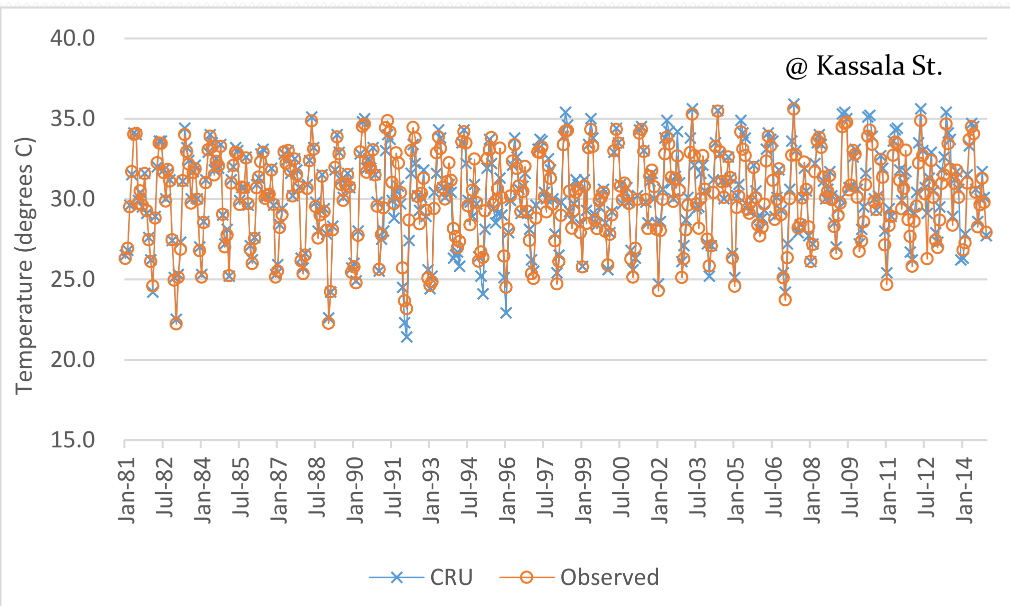
✓ ***CRU-TS*** was used to calculate the average temperature



Example of mean temperature in Jan. 1981
By CRU-TS3.1

# Input Data (Temperature for PET)




- The satellite data has slight differences with the observed data

→ Average correlation coefficient of 26 stations = 0.90

# ***Calculation Model***

- ✓ ***The purpose of the analysis is estimation and understanding of water resources roughly***

→ Because of the target area is the entire Sudan and the limited available data for the analysis

→ Moreover, “Participatory activity by Sudanese C/P for sustainable process” is essential

- ☐ Considering above condition, “**free software, user-friendly (Graphical User Interface, GUI) and simple operation**” are the main criteria for selecting the calculation model
- ☐ Comparison of the major calculation models, which are selected considering the above criteria is as shown on the following page

# Comparison of Calculation Model

| Model name | HEC-HMS | Shetran (GUI version) | Tank model (Excel) | ArcSWAT |
|---|---|---|---|---|
| Data source / Organization | US Army Corps of Engineers | Newcastle University | - | US Department of Agriculture ARS |
| Classification | Distributed (Grid / Sub-basin) | Distributed (Sub-basin model) | Lumped / Distributed (Grid / Sub-basin) | Quasi-distributed (Sub-basin model) |
| Interception of Rainfall | ✓ (vegetation) | ✓ (vegetation) | ✓ (runoff ratio) | ✓ |
| Channel flow | Kinematic wave, etc (select from many options) | 1-dimensional | - | - |
| Last modified | Aug. 2016 | Feb. 2016 | - | - |
| Advantages | ➢ User can select the methods from many options for each element | ➢ Simple and easy with GUI<br>➢ Calculation time is relatively short | ➢ Calculation time is short | ➢ Visually displayed input and output data on the map<br>➢ High-integrity |
| Disadvantages | ➢ Complicated for beginner<br>➢ Calculation time is long with Grid model | ➢ Grid model is not available with GUI version | ➢ Not GUI, but well-known software | ➢ Difficulty in preparation and formulation of all the input data in GIS<br>➢ Long-term observed data is required |

✓ Shetran was used for calculation of the entire Sudan

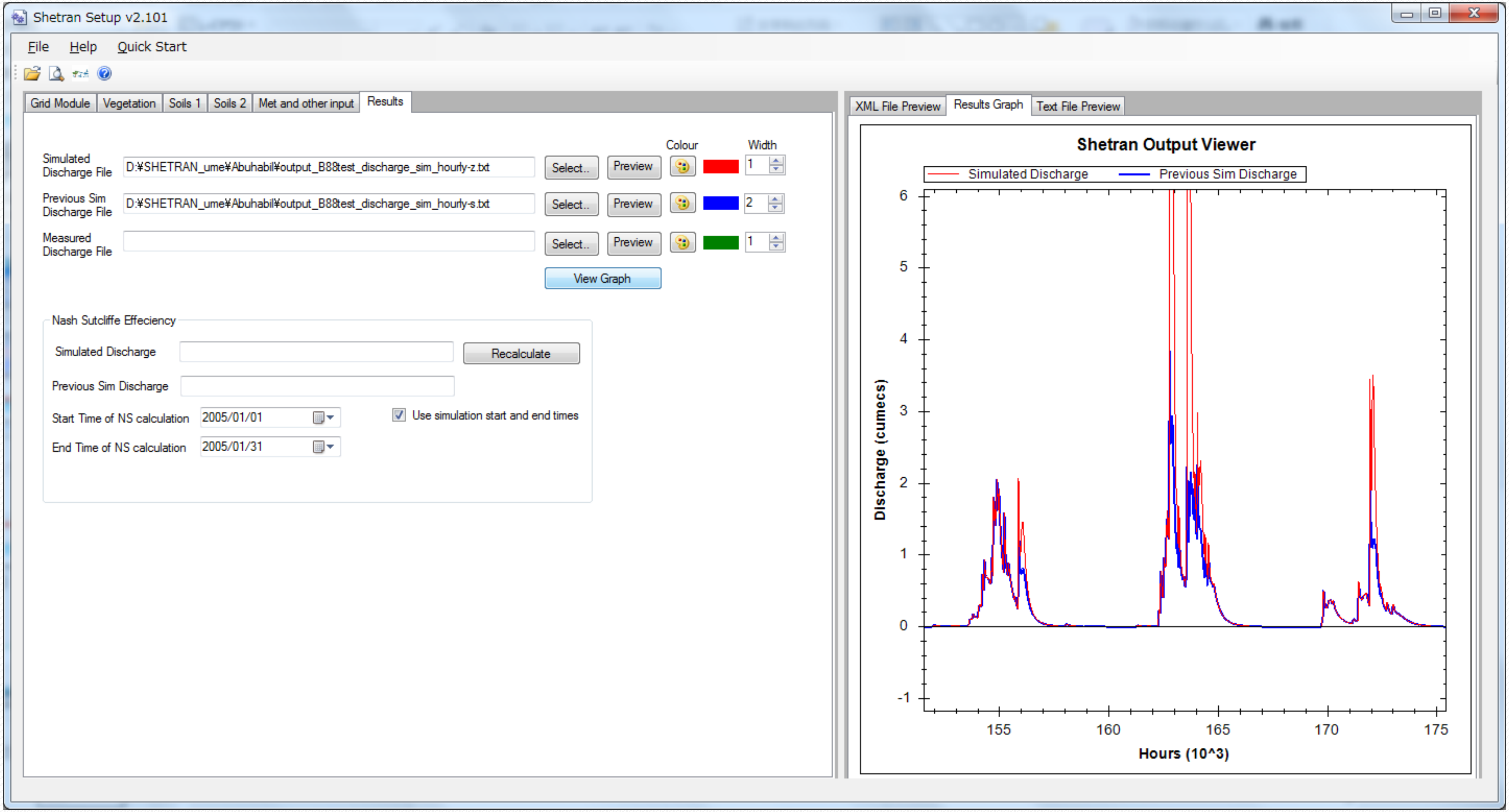
→ It enables C/Ps to operate calculation model simply and quickly

→ It meets the purpose of general calculation of the water potential in the entire Sudan

*Red: Advantage, Blue: Disadvantage, □: Data to be used*

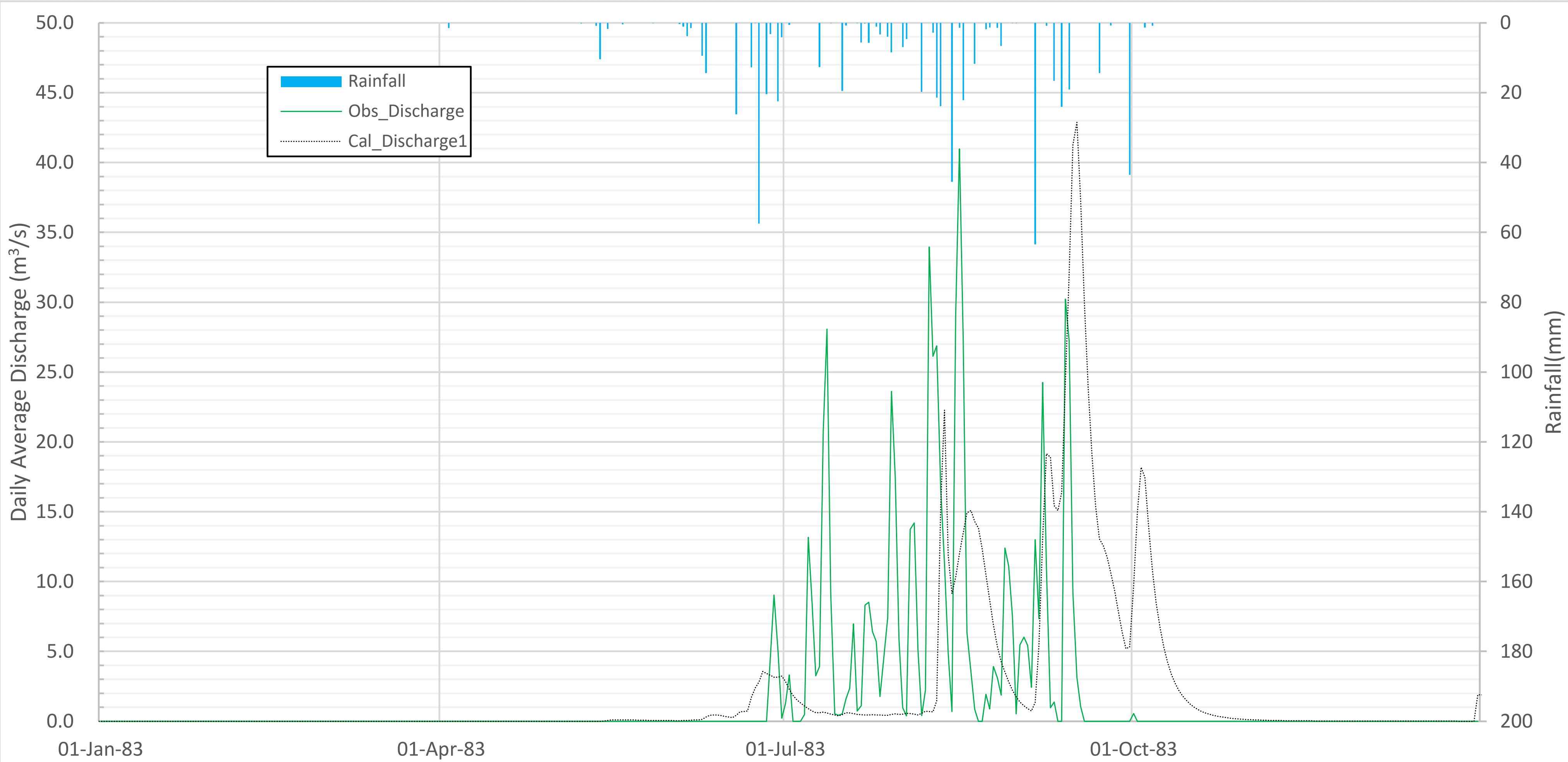
# Calculation result by Shetran

- Example of trial-and-error calculation result

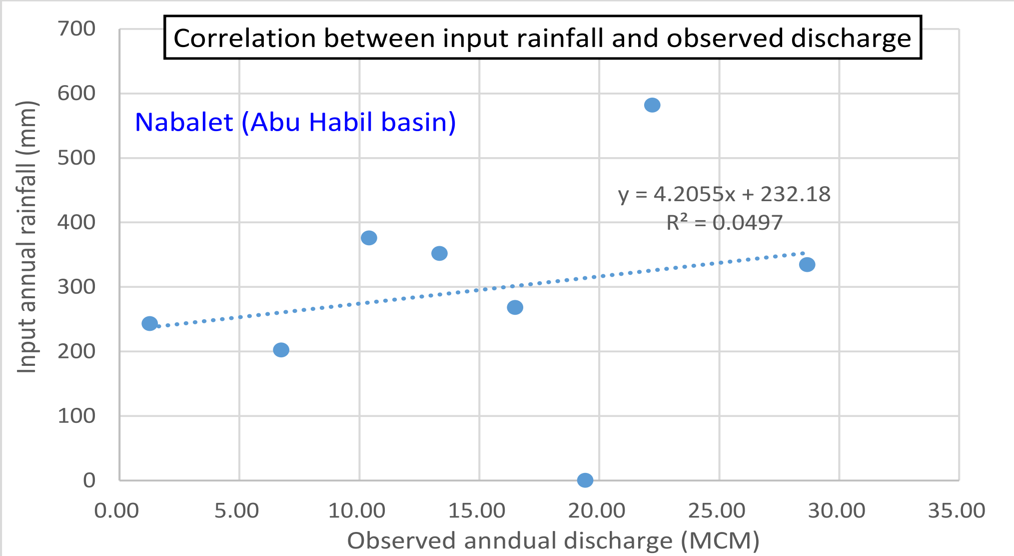


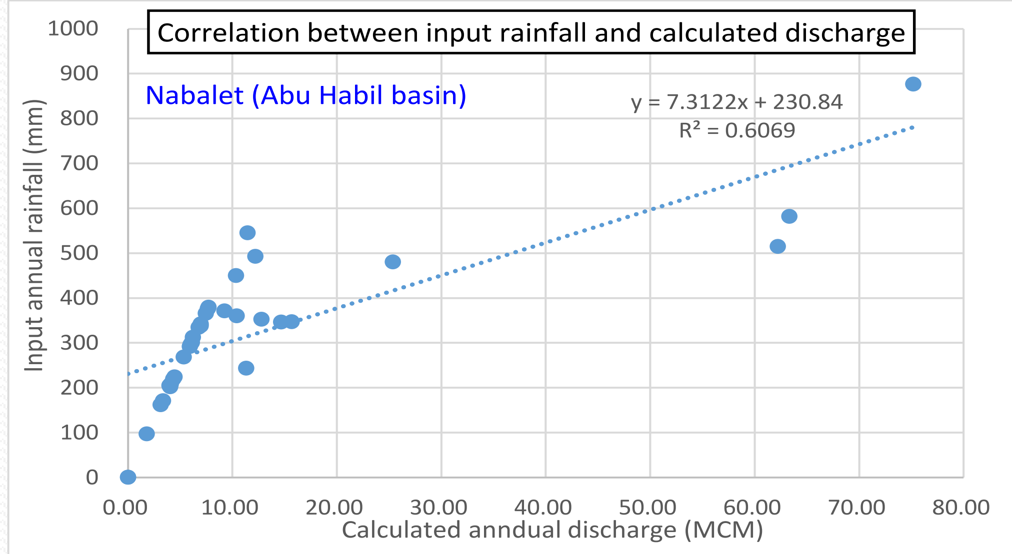
# Calculation result by Shetran

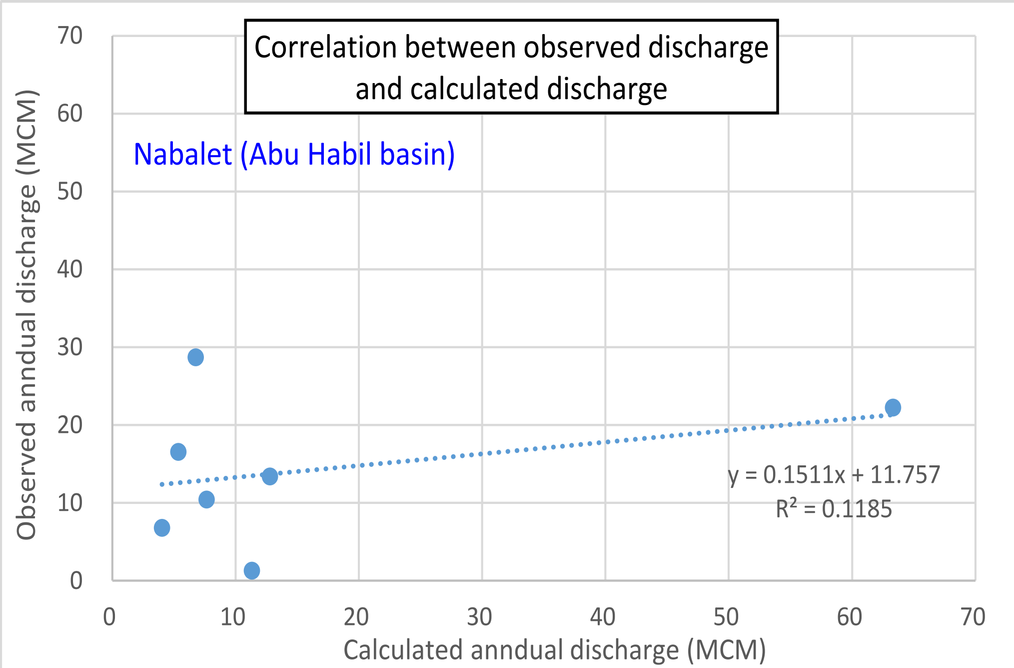
## ◻ Example of calculation / Calibration result (sub-basin 83)



# Comparison of the Observed and Calculated Data




- Input rainfall data before 2000 are based on the limited number of the rainfall station. Therefore, correlation between input rainfall and observed discharge is very weak
- Input rainfall data contributes a great deal to the calculated discharge
  → The discharge calculated by the rainfall, which has weak correlation, resulted a very weak correlation between observed and calculated discharges
- Difficulty in manual observation under the heavy rain and flooded situation might have affected the data accuracy

# Example of the Calculation Result

- ✓ Total annual discharge of surface water in the entire Sudan was estimated as <u>4.05 BCM</u>
- ✓ The calculation result reaches project's objective and is serve as a basis for initial trials
- ✓ **Preparation and calculation for almost all the 180 sub-basins were implemented by the C/Ps with the assistance of the engineers of department of Wadi and Groundwater and the local staffs**

| Sub-basin No. | Clay % | Silt % | Sand % | Catchment Area (km2) | 34-year Average Annual rainfall (mm) | Average annual discharge (MCM)** | Discharge (MCM) / Area (1,000,000m 2) *1,000 (mm) | Runoff ratio d /b | Parameter applied from | Person for Calculation |
|---|---|---|---|---|---|---|---|---|---|---|
| 87 | 46 | 27 | 26 | 8,780.34 | 608.8 | 94.41 | 10.75 | 0.018 | – | Suzan |
| 91 | 22 | 17 | 61 | 12,351.93 | 378.2 | 54.54 | 4.42 | 0.012 | – | El Tyeb |
| 117 | 23 | 29 | 48 | 4,484.18 | 285.5 | 29.59 | 6.60 | 0.023 | – | Safaa |
| 118 | 21 | 34 | 45 | 4,228.02 | 396.4 | 41.29 | 9.77 | 0.025 | – | Um e |
| 187 | 55 | 15 | 30 | 11,395.07 | 81.6 | 9.67 | 0.85 | 0.010 | – | Hind |
| SUM | | | | 1,860,581 | 44,389 | 4,059 | | | | |

– : Calibrated basins

# Efforts for the Calculation

## For rainfall

Download the GSMaP satellite data (CSV format) for 14 years

Open the files with "**GIS / Model Builder**"

Plot the CSV data on the GIS, convert to GIS file, extract by the boundary of Sudan, convert to raster data

Calculation of average rainfall over the sub-basin before 2000 with Thiessen method + Calibration of the 14 years satellite data after 2000

Convert to "Text format" as an input data of the Shetran

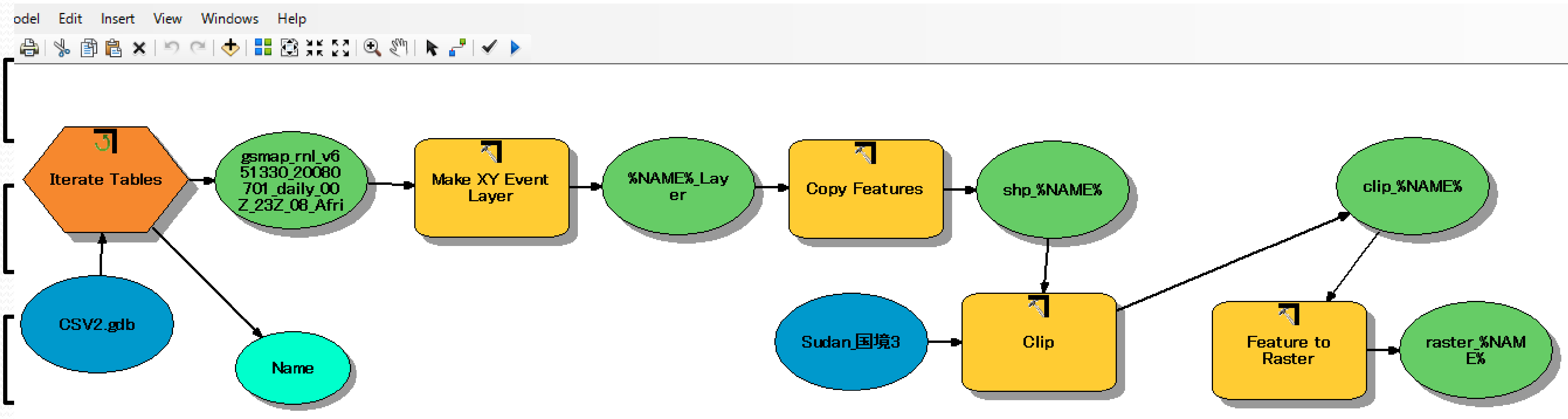
## For potential evapotranspiration (PET)

Download the NetCDF (Network Common Data Form) file of temperature (monthly data)

Open the NetCDF file with "**R language** (programming language)"

Extract 34 years data for every 50 km

(440,640 data in total =1,080 plots × 34 years × 12 months)




Obtained "Hours of daylight"

Calculation of PET for all the sub-basins, then convert to the daily PET

Convert to "Text format" as an input data of the Shetran

# Efforts for the Calculation

## For calculation model

Catchment delineation
(including the several steps of the ArcHydro)

↓

Aggregate the digital elevation map (DEM) to change the calculation grid size (2-10 km) and extract DEM for each sub-basin

↓

Create actual sub-basins for the calculation
(including the several steps of the ArcHydro)

↓

Create DEM data and Mask data by the actual sub-basins for the calculation for each sub-basin
(Some of the sub-basins, especially in Port Sudan, were needed to divided into several sub-sub-basins because there are individual streams directly flow into the Red Sea)

↓

Check and modify the DEM and Mask if it has error

↓

Convert to “ASCII format” as an input data of the Shetran

## For calibration and calculation

Extract “intersected soil classification (soil classification was obtained from FAO)” by each sub-basin

↓

Data organizing of the observed wadi discharge (62 stations) using Excel formulae

↓

Trial-and-error calculation

Set the model parameter (soil, soil layers, river and so on) and run the calculation of the target sub-basins for calibration

↓

Extract and organize the output files

↓

Comparison between observed discharge data and the calculated one (especially for peak discharge and annual volume)

↓

Applying the same model parameters to the similar soil classification and run the calculation of the other sub-basins

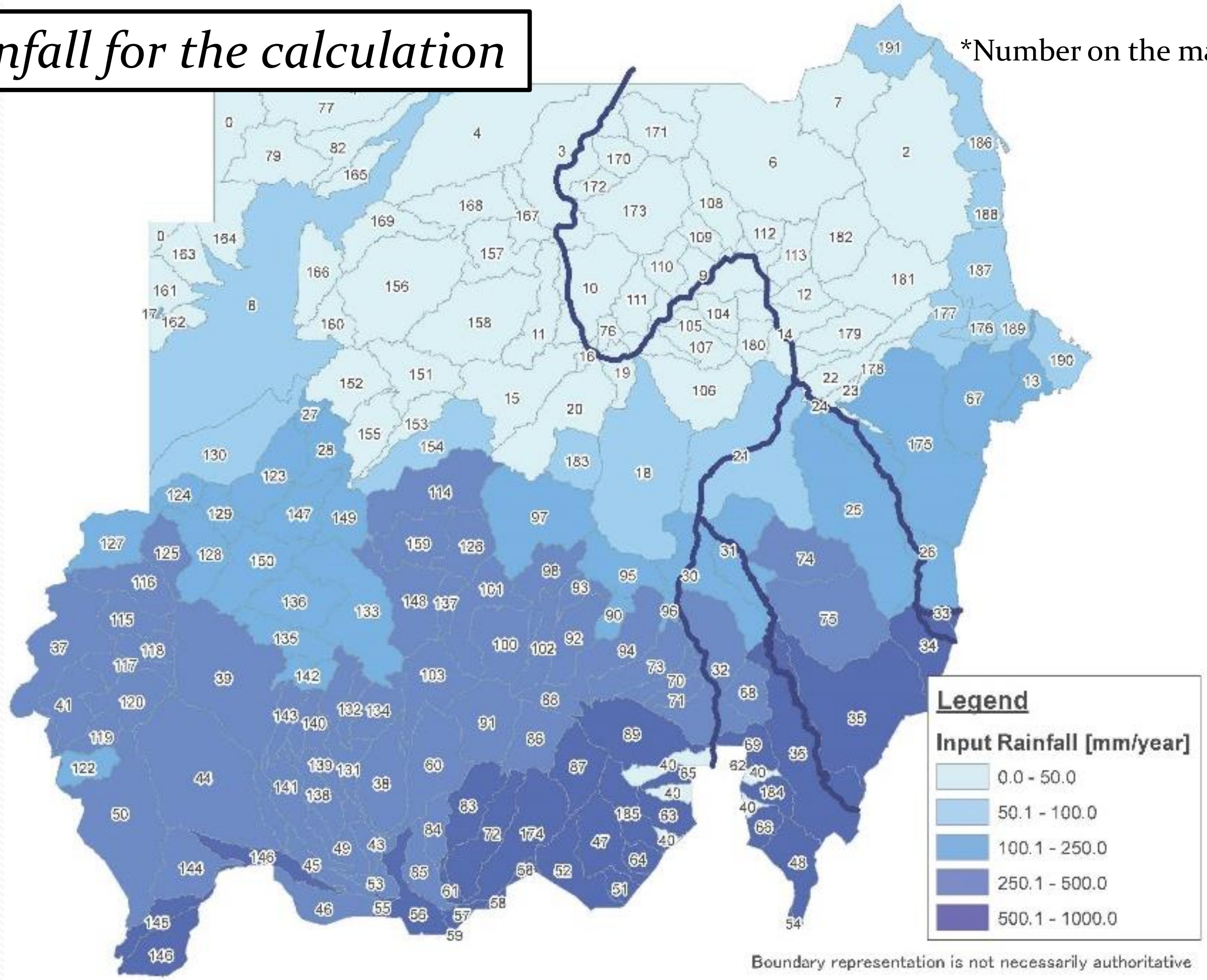
↓

Extract and organize the output files

# Calculation Result of Water Resources Potential on Surface Water in the Entire Sudan

Input rainfall for the calculation

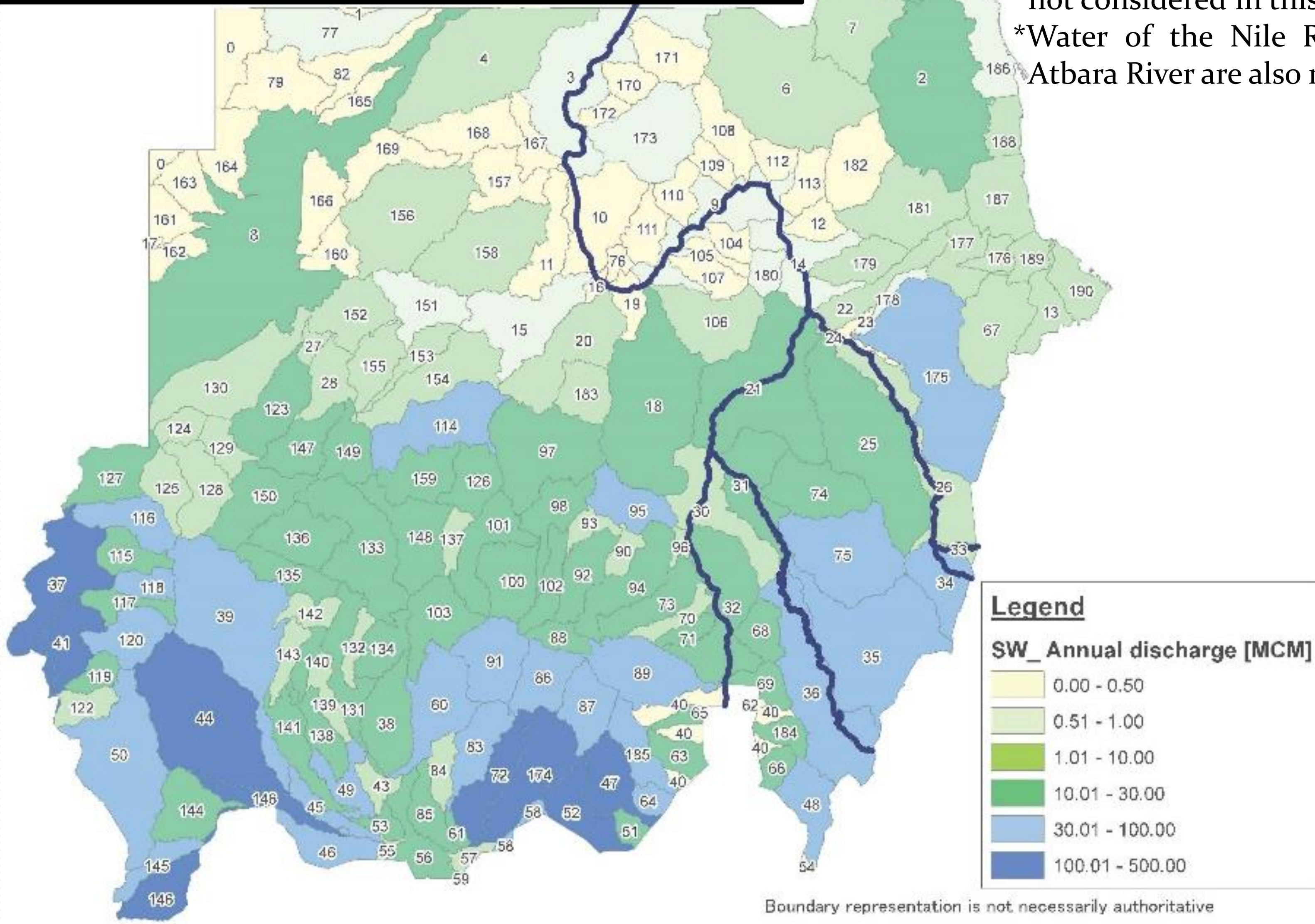
*Number on the map: Sub-basin No.



# Calculation Result of Water Resources Potential on Surface Water in the Entire Sudan

Calculated annual discharge [MCM/year]

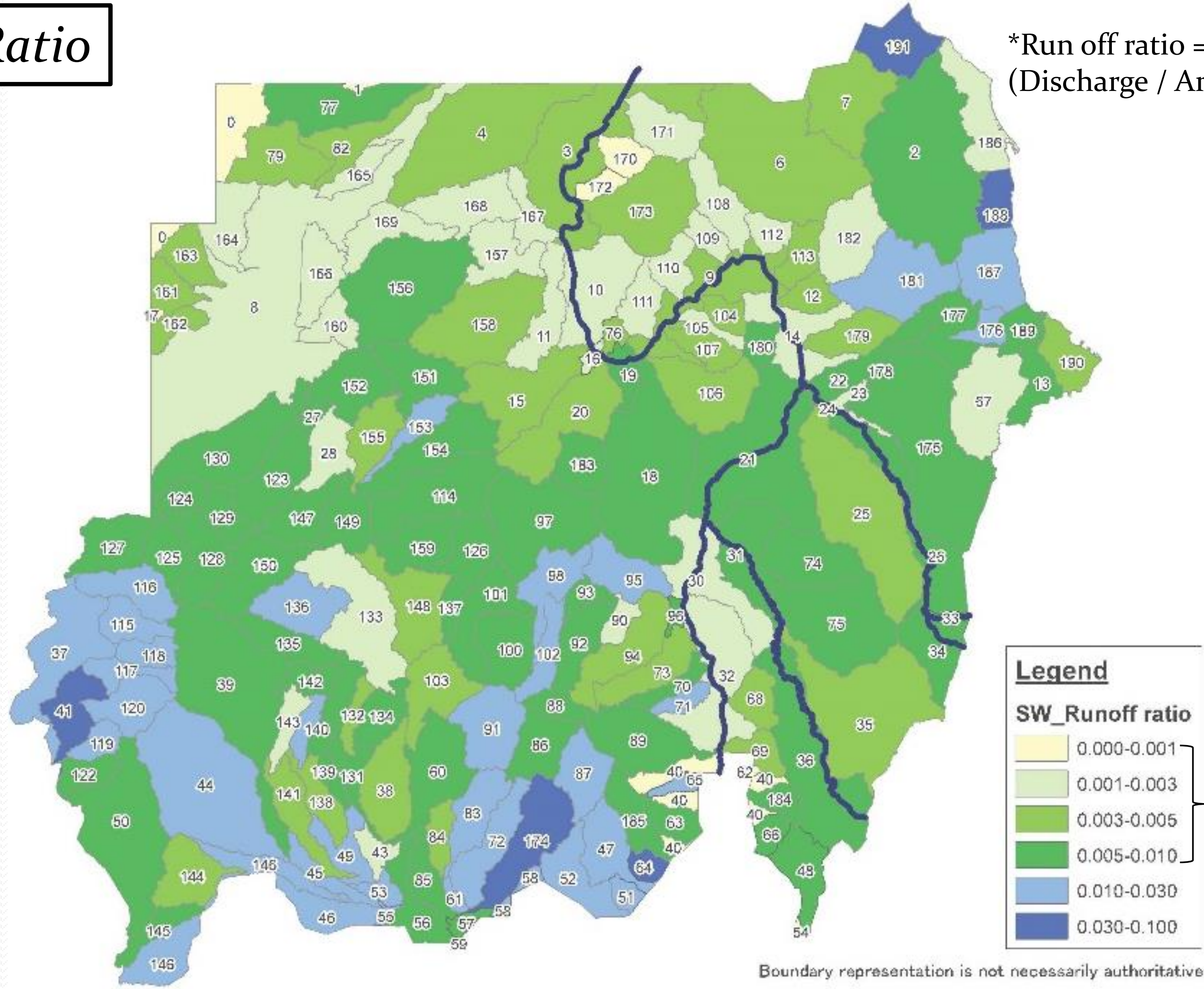
*Water from the outside of Sudan is not considered in this calculation
*Water of the Nile Rivers and the Atbara River are also not considered



# Calculation Result of Water Resources Potential on Surface Water in the Entire Sudan

*Runoff Ratio*

*Run off ratio = (Discharge / Area) / Rainfall

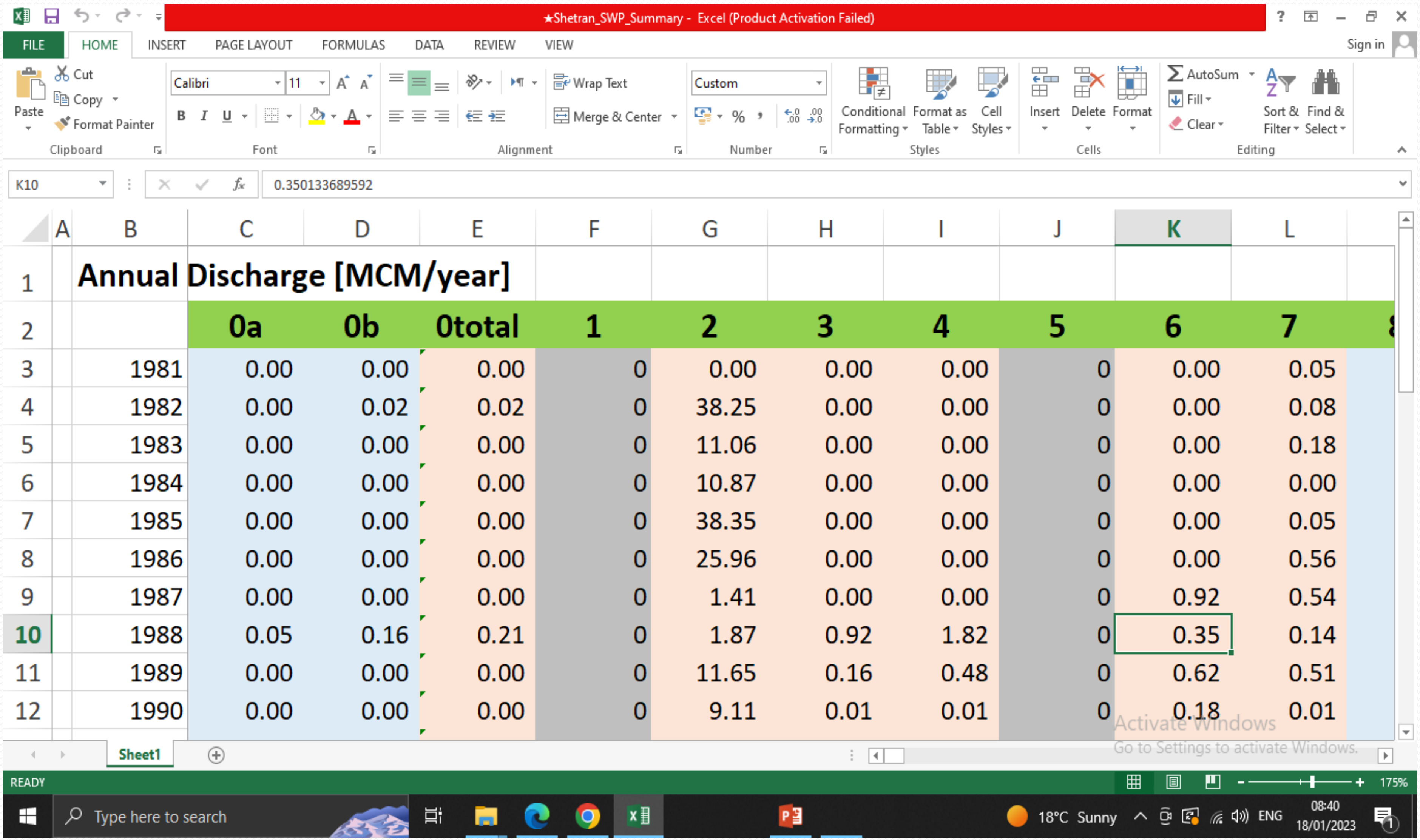



Less than 1 %

# Table 4-13 Calculation Result of Water Resources Potential of Surface Water

| Sub-basin No. | Clay % | Silt % | Sand % | Catchment Area ($km^2$) | 34-year Average Annual rainfall (mm) | Average annual discharge (MCM)** | Discharge(MCM) / Area (1,000,000$m^2$) *1,000 (mm) | Runoff ratio d / b | Parameter applied from |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 20 | 7 | 73 | 10,258.48 | 10.6 | 0.07 | 0.01 | 0.001 | Sand |
| 1 | 20 | 2 | 78 | 529.72 | - | - | - | - | - |
| 2 | 39 | 14 | 46 | 41,599.58 | 49.4 | 13.89 | 0.33 | 0.007 | 177 |
| 3 | 22 | 6 | 68 | 30,415.17 | 7.1 | 0.89 | 0.03 | 0.004 | Sand |
| 4 | 21 | 2 | 77 | 31,706.26 | 7.1 | 1.08 | 0.03 | 0.005 | Sand |
| 5 | - | - | - | - | - | - | - | - | - |
| 6 | 29 | 18 | 52 | 38,731.77 | 9.1 | 1.45 | 0.04 | 0.004 | 118 |
| 7 | 43 | 16 | 41 | 14,648.12 | 22.6 | 1.35 | 0.09 | 0.004 | 177 |
| 8 | 20 | 3 | 77 | 80,783.66 | 67.9 | 14.93 | 0.18 | 0.003 | Sand |
| 9 | 31 | 15 | 53 | 16,824.36 | 12.8 | 0.67 | 0.04 | 0.003 | 177 |
| 10 | 30 | 19 | 50 | 15,860.05 | 11.3 | 0.49 | 0.03 | 0.003 | 177 |
| 11 | 23 | 18 | 59 | 8,842.91 | 11.0 | 0.20 | 0.02 | 0.002 | 177 |
| 12 | 30 | 31 | 40 | 4,143.82 | 23.9 | 0.34 | 0.08 | 0.003 | 177 |
| 13 | 48 | 17 | 36 | 6,317.68 | 114.0 | 3.81 | 0.60 | 0.005 | 187 |
| 14 | 27 | 27 | 45 | 11,848.05 | 38.5 | 0.64 | 0.05 | 0.001 | 177 |
| 15 | 20 | 3 | 77 | 16,748.51 | 11.6 | 0.88 | 0.05 | 0.005 | Sand |
| 16 | 21 | 25 | 52 | 1,193.34 | 12.5 | 0.02 | 0.02 | 0.001 | SCL+Sand |
| 17 | 20 | 5 | 75 | 245.28 | 121.7 | - | - | - | Sand |
| 18 | 32 | 16 | 51 | 35,869.77 | 71.9 | 14.82 | 0.41 | 0.006 | SandClay |
| 19 | 26 | 15 | 58 | 4,152.26 | 14.3 | 0.35 | 0.08 | 0.006 | SCL+Sand |
| 20 | 28 | 8 | 63 | 16,830.98 | 44.3 | 3.30 | 0.20 | 0.004 | SCL+Sand |
| 21 | 37 | 23 | 39 | 35,560.29 | 66.6 | 12.68 | 0.36 | 0.005 | 74 |
| 22 | 37 | 21 | 42 | 8,792.81 | 44.9 | 2.53 | 0.29 | 0.006 | 177 |
| 23 | 35 | 22 | 43 | 1,715.52 | 46.8 | 0.10 | 0.06 | 0.001 | 177 |
| 24 | 39 | 26 | 35 | 11.46 | - | - | - | - | - |
| 25 | 43 | 27 | 30 | 33,545.45 | 207.3 | 24.10 | 0.72 | 0.003 | 74 |
| 26 | 41 | 26 | 32 | 7,091.54 | 237.3 | 9.87 | 1.39 | 0.006 | 74 |
| 27 | 22 | 5 | 73 | 1,832.13 | 127.1 | 1.18 | 0.64 | 0.005 | Sand |

| Sub-basin No. | Clay % | Silt % | Sand % | Catchment Area ($km^2$) | 34-year Average Annual rainfall (mm) | Average annual discharge (MCM)** | Discharge(MCM) / Area (1,000,000$m^2$) *1,000 (mm) | Runoff ratio d / b | Parameter applied from |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 20 | 4 | 75 | 10,356.43 | 289.5 | 18.03 | 1.74 | 0.006 | Sand |
| 101 | 25 | 14 | 61 | 10,846.89 | 283.1 | 28.22 | 2.60 | 0.009 | 88 |
| 102 | 21 | 6 | 73 | 5,778.78 | 298.3 | 20.30 | 3.51 | 0.012 | Sand |
| 103 | 22 | 6 | 71 | 11,104.77 | 354.2 | 13.22 | 1.19 | 0.003 | 60 |
| 104 | 43 | 19 | 38 | 3,287.44 | 16.1 | 0.22 | 0.07 | 0.004 | 177 |
| 105 | 33 | 12 | 54 | 2,311.55 | 18.9 | 0.09 | 0.04 | 0.002 | 177 |
| 106 | 34 | 16 | 50 | 14,479.58 | 38.4 | 2.04 | 0.14 | 0.004 | 177 |
| 107 | 43 | 19 | 38 | 4,984.80 | 18.8 | 0.41 | 0.08 | 0.004 | 177 |
| 108 | 20 | 6 | 74 | 7,752.72 | 9.8 | 0.21 | 0.03 | 0.003 | Sand |
| 109 | 20 | 3 | 78 | 3,286.41 | 10.3 | 0.05 | 0.01 | 0.001 | Sand |
| 110 | 21 | 5 | 74 | 4,744.17 | 13.4 | 0.18 | 0.04 | 0.003 | Sand |
| 111 | 28 | 14 | 58 | 5,762.19 | 11.2 | 0.19 | 0.03 | 0.003 | 118 |
| 112 | 21 | 34 | 45 | 3,508.00 | 11.8 | 0.08 | 0.02 | 0.002 | 118 |
| 113 | 28 | 27 | 45 | 5,180.67 | 11.8 | 0.22 | 0.04 | 0.004 | 118 |
| 114 | 22 | 3 | 75 | 16,749.19 | 322.0 | 32.75 | 1.96 | 0.006 | Sand |
| 115 | 20 | 35 | 45 | 5,933.78 | 286.0 | 22.76 | 3.84 | 0.013 | 118 |
| 116 | 22 | 34 | 44 | 8,666.87 | 334.7 | 38.56 | 4.45 | 0.013 | 118 |
| 117 | 23 | 29 | 48 | 4,484.18 | 285.5 | 29.59 | 6.60 | 0.023 | - |
| 118 | 21 | 34 | 45 | 4,228.02 | 396.4 | 41.29 | 9.77 | 0.025 | - |
| 119 | 46 | 20 | 34 | 3,628.55 | 396.4 | 23.32 | 6.43 | 0.016 | 118 |
| 120 | 35 | 25 | 39 | 8,821.76 | 408.2 | 51.53 | 5.84 | 0.014 | 118 |
| 121 | - | - | - | - | - | - | - | - | - |
| 122 | 44 | 29 | 27 | 4,723.83 | 150.0 | 6.22 | 1.32 | 0.009 | 118 |
| 123 | 21 | 8 | 72 | 11,599.15 | 158.1 | 10.01 | 0.86 | 0.005 | Sand |
| 124 | 23 | 7 | 70 | 3,651.31 | 158.1 | 5.54 | 1.52 | 0.010 | Sand |
| 125 | 34 | 11 | 55 | 6,294.06 | 255.8 | 9.02 | 1.43 | 0.006 | 118 |
| 126 | 26 | 12 | 62 | 7,731.30 | 255.8 | 16.37 | 2.12 | 0.008 | 88 |
| 127 | 25 | 13 | 62 | 10,040.89 | 165.6 | 15.13 | 1.51 | 0.009 | 118 |



Annual Discharge [MCM/year]

| | 0a | 0b | 0total | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.05 |
| 1982 | 0.00 | 0.02 | 0.02 | 0 | 38.25 | 0.00 | 0.00 | 0 | 0.00 | 0.08 |
| 1983 | 0.00 | 0.00 | 0.00 | 0 | 11.06 | 0.00 | 0.00 | 0 | 0.00 | 0.18 |
| 1984 | 0.00 | 0.00 | 0.00 | 0 | 10.87 | 0.00 | 0.00 | 0 | 0.00 | 0.00 |
| 1985 | 0.00 | 0.00 | 0.00 | 0 | 38.35 | 0.00 | 0.00 | 0 | 0.00 | 0.05 |
| 1986 | 0.00 | 0.00 | 0.00 | 0 | 25.96 | 0.00 | 0.00 | 0 | 0.00 | 0.56 |
| 1987 | 0.00 | 0.00 | 0.00 | 0 | 1.41 | 0.00 | 0.00 | 0 | 0.92 | 0.54 |
| 1988 | 0.05 | 0.16 | 0.21 | 0 | 1.87 | 0.92 | 1.82 | 0 | 0.35 | 0.14 |
| 1989 | 0.00 | 0.00 | 0.00 | 0 | 11.65 | 0.16 | 0.48 | 0 | 0.62 | 0.51 |
| 1990 | 0.00 | 0.00 | 0.00 | 0 | 9.11 | 0.01 | 0.01 | 0 | 0.18 | 0.01 |