ADB

Technical Assistance Consultant’s Report

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July 2018

Knowledge and Innovation Support for ADB's Water Financing Program

Indonesia: Water Accounting in Jratun Seluna, Cimanuk Cisanggarung, Deli-Percut-Belawan and Seputih Tulang Bawang River Basins

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For Asian Development Bank

Asian Development Bank

Water Accounting in Indonesia

Pilot studies on Java and Sumatra

Final report

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1 Executive Summary

1. The improvement of water security and addressing water scarcity is one of the major economic development priorities for Indonesia. The Asian Development Bank (ADB) is preparing the Enhanced Water Security Investment Project (EWSIP) which aims to support the Government of Indonesia to improve water security. The objectives of the project as described in the EWSIP Project Concept Paper are the following:

- improving water resources planning and management to meet rising demands for irrigation and non-agricultural users
- minimizing spatial variations in water availability by improving water storage facilities and conveyance
- increasing resilience to climate change

2. Water accounting can provide a coherent and consistent methodology for quantifying hydrological processes and the distribution of water over various competing sectors. It also considers the consumption of water and the benefits and services - including ecosystem services - that result from that consumption, including the return flow of non-consumed water.

3. The Water Accounting Plus system (WA+) is based on open access remote sensing data – in conjunction with open access GIS data and hydrological model output. WA+ communicates information on water storage, flows and fluxes for a variety of land use systems using a number of intuitive resource sheets, tables and maps that are designed to be understood by people with technical and non-technical backgrounds alike. The WA+ framework is developed by IHE-Delft in partnership with the International Water Management Institute, the Food and Agriculture Organization, and the World Water Assessment Program.

4. The main objective of this project is to support the formulation of the proposed Enhanced Water Security Investment Program (EWSIP) with an independent assessment of water fluxes and consumption in four selected river basins.

5. The two main components of the project are:

- Application of the WA+ procedure to estimate, on a monthly scale, available and exploitable water resources for four pilot river basins.
- Training and capacity building on the WA+ system, including but not limited to: basic hydrology, GIS, remote sensing data, WA concepts, interpretation of WA+ results.

6. The project started in September 2017, the first Inception Workshop and consultation with different national stakeholders was held in January 2018. The project ended in July 2018.

7. The water accounting plus framework was applied to 4 pilot basins in Indonesia: Seluna and Cimanuk Cisanggarung River Basins in Java Island; and Deli-Percut-Belawan and Seputih-Tulang Bawang river basins in Sumatra Island. In this report, for each basin, the results are presented for a wet, an average and a dry year selected from the period 2008-2014.

8. The main observations are:

- On a basin and yearly scale, all four pilot basins were found to have sufficient water resources under current conditions.

- Inter-annual variability in water availability is very high
- Seasonal water availability is very variable for all basins with particularly high variability for the Cimanuk, Jratunseluna and Seputih basins. This has the following consequences:
    - Reliance on storages in the dry season
    - No utilizable flow left-over in dry season
    - High utilizable outflow during the wet season (except for the Jratunseluna basin). These outflows could be stored for use in the dry season.
- Non recoverable outflows are high for the two basins located on Java Island
- Jratunseluna is the basin for which the water situation is the most difficult due to a long period of negative water yields coupled with a high rate of water pollution.
- Scenarios from climate models predict that precipitation will increase in wet months and decrease in dry months over Indonesia, thereby further increasing the current seasonal water availability disparities (see for example http://sdwebx.worldbank.org/climateportal/).
- High utilizable outflows in the wet season should be stored for use in the dry season through carefully planned surface water storages
- Low water productivities indicate potential for increased production without additional water supply
    - In a water productivity study, Cai et al. (Water Productivity Assessment for Improved Irrigation Performance and Water Security in the Asia-Pacific Region: Indonesia, 2018) found that in their study areas in Indonesia examples of high and low water productivity areas could be found and recommended analyzing high performing areas to help inform potential improvements in low-performing areas.
- Field application efficiencies are low, and non-beneficial ET was found to be between 30 and 55% of total ET
    - Irrigations amounts could be reduced further during times of high rainfall
    - On-farm water conservation techniques should be used (see also Cai et al., 2018)

9. Note that this report describes main results only, all the accounting sheets will be made available on our http://www.wateraccounting.org in July 2018.

2 Introduction

10. The Asian Development Bank (ADB) is preparing the Enhanced Water Security Investment Project (EWSIP) which aims to support the Government of Indonesia to improve water security. The objectives of the project as described in the EWSIP Project Concept Paper are the following:

- improving water resources planning and management to meet rising demands for irrigation and non-agricultural users
- minimizing spatial variations in water availability by improving water storage facilities and conveyance
- increasing resilience to climate change

11. Considerable progress has been made in many countries in processing and storage of basic geographic information systems (GIS) data. Yet routine access to this information contained in servers is often restricted to the host organization and the agency that "owns" the data. This limits the benefits that could be obtained by wider use and sharing with other agencies.

12. Information on water resources has to be coherent and synchronized in order to provide an integrated picture useful for the assessment of the problems and possible solutions. The current democracy on hydrological data does not provide the required data necessary to all stakeholders. This hampers the development of good water stewardship. Dissimilar sources of information and terminologies jeopardize the transparency necessary for joint decisions on water, land and ecosystems. Hence, there is a need for independently gathered water resources related data sets that can be commonly understood by all parties.

13. Water accounting can meet this requirement. It provides a coherent and consistent methodology that quantifies hydrological processes, water storage, base flow, and the distribution of water to various competing sectors. It also considers the consumption of water and the benefits and services - including ecosystem services - that result from that consumption, including the return flow of non-consumed water. A water accounting system based on open access earth observation satellite data for complete river basins - including transboundary basins - is therefore proposed: The Water Accounting Plus system (WA+). It goes beyond the classical description of water supply and water demand, and describes all hydrological and physical water management processes in a river basin.

14. The concept of conducting country water assessments as a means to plan for improved national water security was suggested in the ADB Water Operational Plan 2011-2020. Subsequently, the Asia Water Development Outlook 2013 made a first attempt to quantify national water security, using five key dimensions: (i) household water security, (ii) economic water security, (iii) urban water security, (iv) environmental water security and (v) resilience to water related disasters. In 2013 and 2016, the National Water Security Index (NWSI) of Indonesia was Stage 2: Engaged.

15. At the core of the activity now proposed is a complementary "water accounting" procedure. Essential to the concept of the ADB country water assessments is the element of water demand

forecasting, per economic sector (agriculture, industry, energy and municipal), vs. the surface water and groundwater resources for each (major) river basin.

16. This final report follows an action plan submitted in October 2015 and reflects an approved proposal from IHE-Delft to assist ADB with water accounting.

17. The point of contact from ADB Indonesia Resident Mission is Senior Water Resources Specialist Eric Quincieu. The Principal Investigator from IHE-Delft is Dr. Wim Bastiaanssen. Dr. Claire Michailovsky, Water Accounting Expert of IHE-Delft, is responsible for the implementation of WA+ in the 4 pilot basins in Indonesia.

3 Methodology

18. The Water Accounting Plus (WA+) framework is developed by IHE-Delft in partnership with the International Water Management Institute (IWMI), the Food and Agriculture Organization (FAO), and the World Water Assessment Program (WWAP). It is a multi-institutional effort that aims to provide a valuable and reliable source of information regarding presence and utilization of water resources. The WA+ framework communicates information on water storage, flows and fluxes for a variety of land use systems using a number of intuitive resource sheets that are designed to be understood by people with technical and non-technical backgrounds alike (see Figure 1 for an example of the current version of the WA+ Sheets).

19. The WA+ framework focuses on the use of public access remote sensing data in an effort to maintain a high level of transparency. Data products from the National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) are provided free of charge for all users regardless of nationality and intended application. Datasets of topography, precipitation, evapotranspiration, soil moisture, net primary production, land use, water surface areas and water levels can be downloaded or determined from the raw satellite data.

20. The Water Accounting + reporting is based on sheets, tables and maps. Maps created from remote sensing, GIS and hydrological models form the basis of distributed computations on flows, fluxes and storage changes. This data is then compiled by Land Use - Land Cover (LULC) class. Class average values form the skeleton for presenting the results in the sheets. The results are also presented by means of tributaries and rivers; the monthly discharge at any point in the basin with a spatial resolution of 250 m can be computed.

21. Software has been developed to read data from various open access data sources and convert the input data into added value hydrological and water management information. All scripts are written in the Python language, a freeware which is highly suitable for the processing of spatial data sets. Supporting scripts are made for the conversion of the information into the standard WA+ fact sheets.

22. More background information can be found at www.wateraccounting.org. The software to perform computations and produce the accounting sheets is available free and open source on GitHub: https://github.com/wateraccounting.

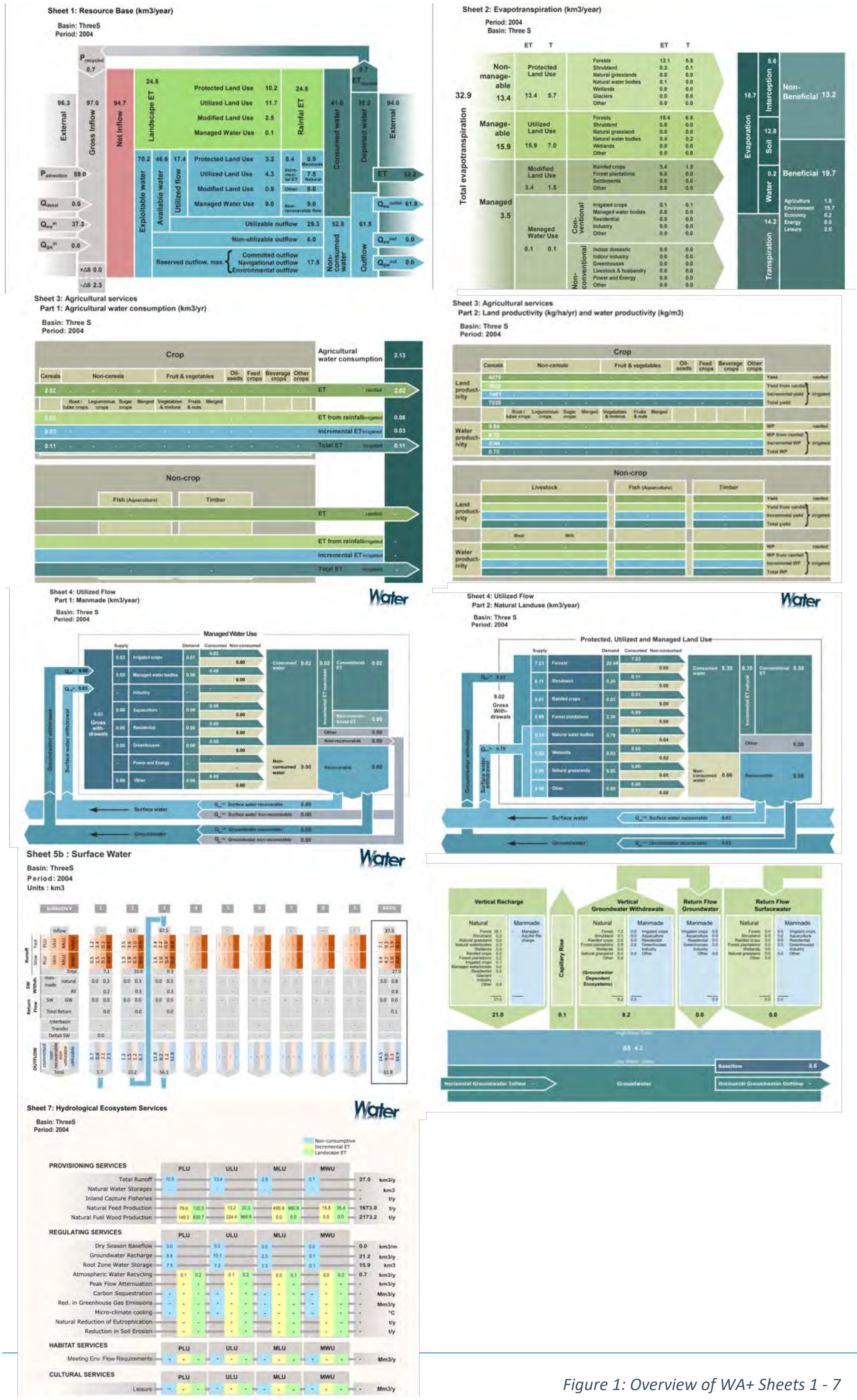

Figure 1: Overview of WA+ Sheets 1 - 7

4 Objectives

23. The main objective of this project is to support the formulation of the proposed Enhanced Water Security Investment Program (EWSIP) with an independent assessment of water fluxes and consumption in the four selected river basins: (i) Seluna and Cimanuk Cisanggarung River Basins in Java island; and (ii) Deli-Percut-Belawan and Seputih-Tulang Bawang river basins in Sumatra island

24. The two main components of the project are:

(a) Application of the WA+ procedure to estimate, on a monthly scale, available and exploitable water resources for the pilot river basins. Monthly and yearly accounts will be produced for the years 2008-2014 (when all higher resolution data is available). And the analysis for each basin will focus on 3 years representing dry, average and wet conditions. The differences between these 3 years will be interpreted in the context of expected future climate change for the region, spatial variability will be interpreted in the context of land use change scenarios.

(b) Training and capacity building on the WA+ system, including but not limited to: basic hydrology, GIS, remote sensing data, WA concepts, interpretation of WA+ results. Certificates will be distributed to successful training participants.

25. The WA+ project work in Indonesia was carried out between September 2017 and June 2018.

4.1 Key Deliverables

- Standardized WA+ fact sheets 1-7, tables and maps uploaded on the www.wateraccounting.org open-access data repository, for the selected historical years in the period 2008-2014 (wet, dry and average year) with monthly time scales, and 250m resolution, for the 4 pilot basins.
- Water Security Diagnosis (i.e. interpretation of the produced fact sheets) and sensitivity analysis of future climate change and land use change
- Input into Asian Water Development Outlook
- Training and capacity building on the WA+ system
- Scripts and tools transferred to the main recipient organizations
- Inception and final report.

5 Workshops and Trainings

5.1 Inception mission and Stakeholder consultation

26. The WA+ team and local stakeholders met in Jakarta between January 29th and February 2nd 2018. A general stakeholder meeting was held at the Ministry of Public Works, and separate meetings were held with a number of local stakeholders.

27. Key local partners participating in the stakeholder meeting were the following:

28. BMKG (Badan Meteorologi Klimatologi dan geofisika)

29. BIG (Badan Informasi Geospasial)

30. LAPAN (lembaga penerbangan dan antariksa nasional)

31. PUSAIR (Pusat penelitian dan pengembangan sumber daya air = Center for research and development of water resources)

32. It was planned to involve employees of these institutions in the WA+ training sessions. Local universities (ITB, IPB in particular) were also identified as potential recipients of capacity building activities.

33. Availability of local datasets was discussed with local stakeholders, with PUSAIR and BMKG planning to cooperate on account validation through discharge and precipitation data sharing.

5.2 Training Workshop June 2018

34. A WA+ training workshop was held in Bandung, Indonesia on the 28th, 29th and 30th of June 2018.

35. Participants from Indonesian institutions including the Ministry of Public Works, PUSAIR, BMKG, LAPAN and Universities were present.

36. The participants were given lectures on all water accounting sheets, the theory behind them and on the interpretation of WA+ results.

37. The participants were also given also hands-on training on the use of GIS software (QGIS) for the analysis of remote-sensing as well on how and where to download some major datasets (Landsat and CHIRPS data).

6 Input data and preliminary data analysis

38. The WA+ procedure is strongly based on the use of Remote Sensing and open-access datasets. It is however important to validate (and possibly improve or correct) these data with locally obtained data to ensure reliable results.

39. In the following section we present some of the in situ and remote sensing datasets which have already been obtained as well as some preliminary data analysis.

40. The boundaries of the 4 selected study areas, 2 on Java (Cimanuk-Cisanggarung and Jratun-Seluna) and 2 on Sumatra (Belawan-Ular-Padang and Seputih-Sekampung), were provided by the Ministry of Public Works and are shown in Figure 2.

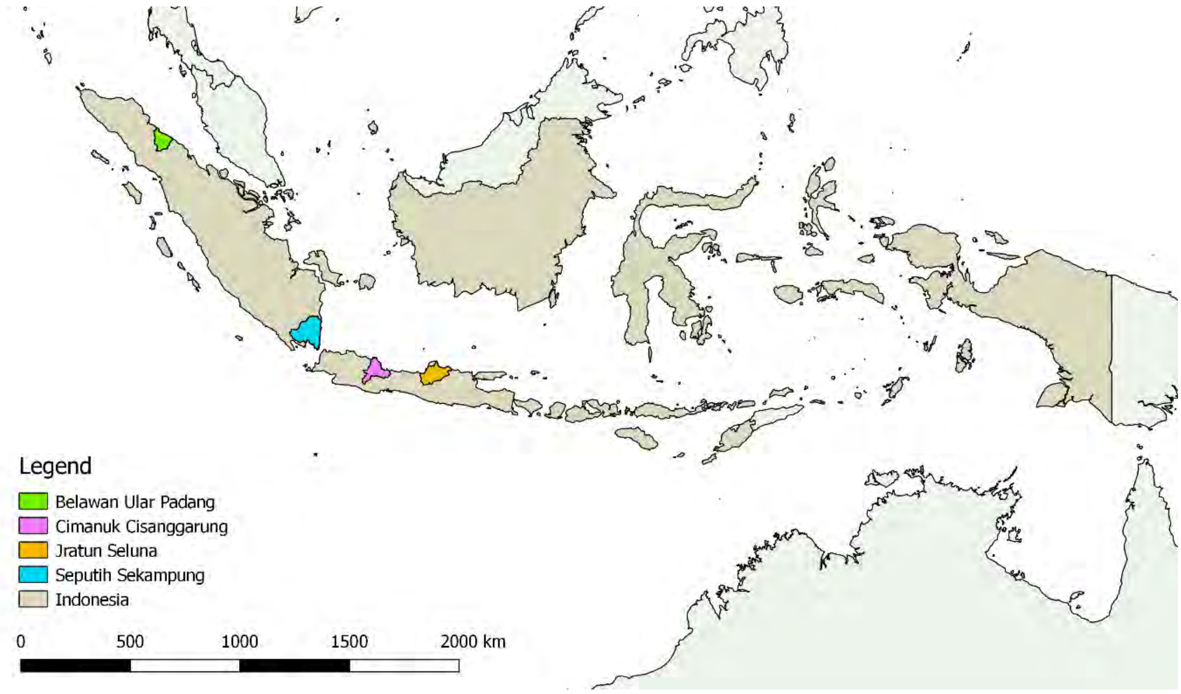

Figure 2: Location of the 4 pilot basins for the WA+ study

6.1 Land Use Land Cover (LULC)

41. The land use land cover map is one of the key inputs for the WA+ procedure because it enables the split of water uses between different sectors as well as the computation of water and land yields per crop type. Land cover maps for the study areas were provided by the Ministry of Forestry through ADB (Figure 3).

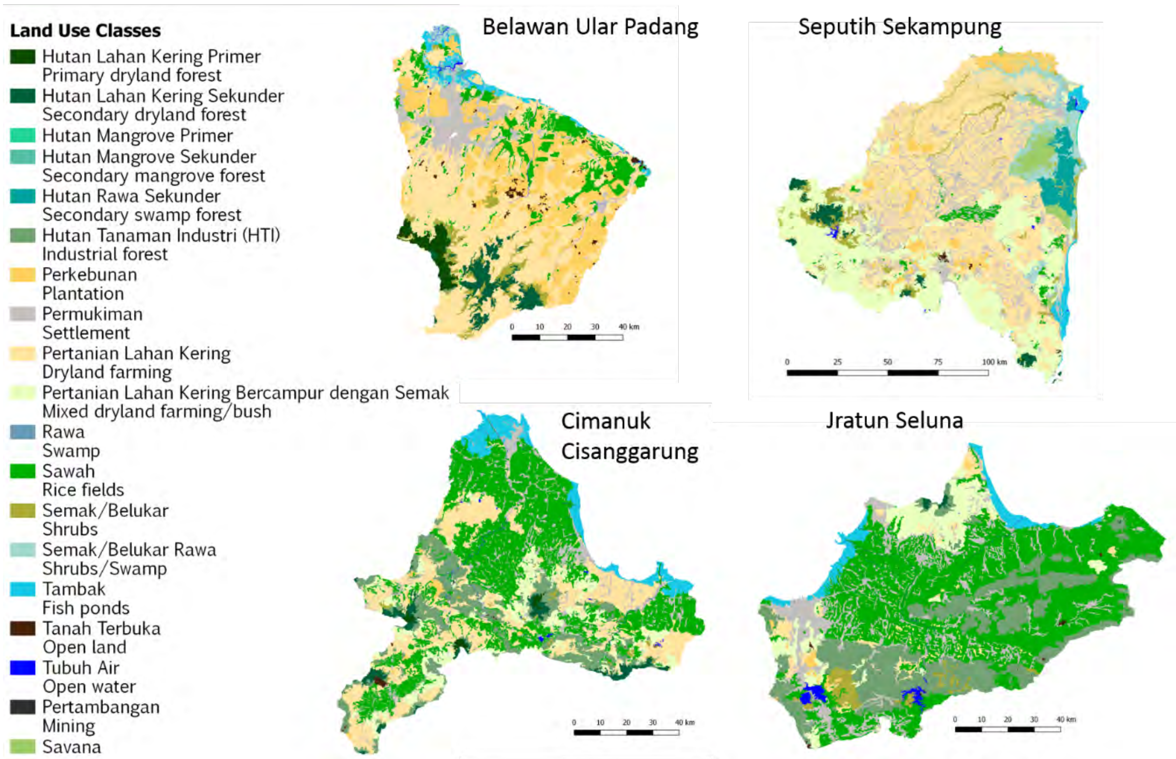

Figure 3: LULC maps for the study areas

42. To produce the final Land Use Land Cover (LULC) map according to the standard Water Accounting + classification (80 possible classes), we combined the information from this map with other open access data, namely:

- the map of protected areas obtained from the World Database of Protected Areas (https://www.protectedplanet.net)
- irrigation map referring to the period 2000-2010, produced by the International Water Management Institute (http://waterdata.iwmi.org/applications/irri_area).

43. Figure 4 shows the final WA+ land use classification output obtained for 4 basins.

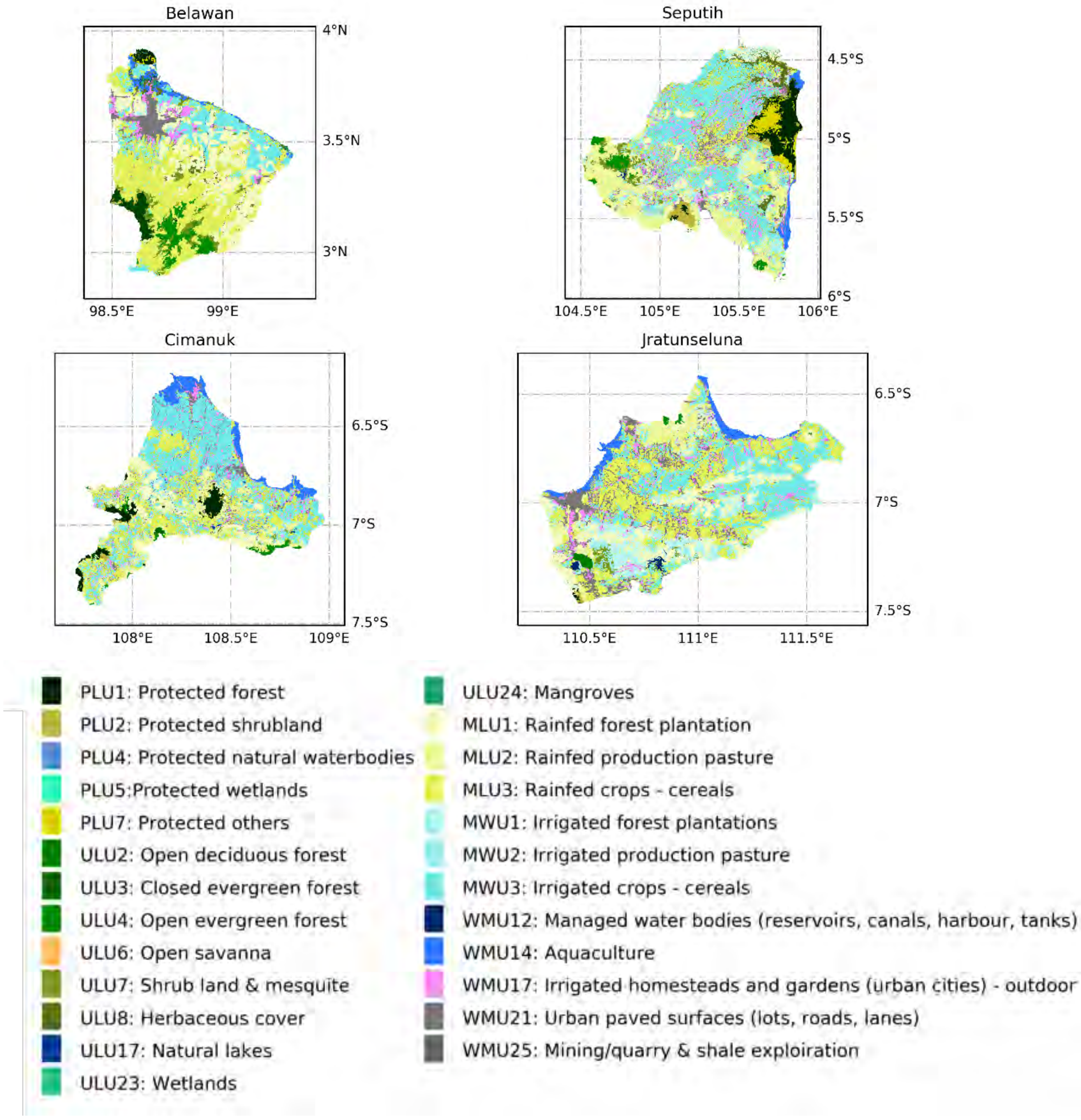

Figure 4: WA+ LULC classification for the 4 basins

44. The classes are grouped into 4 major management groups:

- Protected Land Use (PLU)
- Utilized Land Use (ULU): these are land uses which are still in their "natural" state but which are utilized. For example natural grasslands which are used for grazing.
- Modified Land Use (MLU): these are land uses which have been changed from their natural state, for example rainfed crops.
- Managed Water Use (MWU): these are land uses for which the water supply is directly managed, for example irrigated crops.

45. These distinctions are made as the water management options available will be different for each of these groups.

6.2 Digital Elevation Model (DEM)

46. Digital Elevation maps were downloaded from HydroSHEDS which is a hydrologically conditioned elevation dataset based on elevation data from NASA's Shuttle Radar Topography Mission (SRTM).

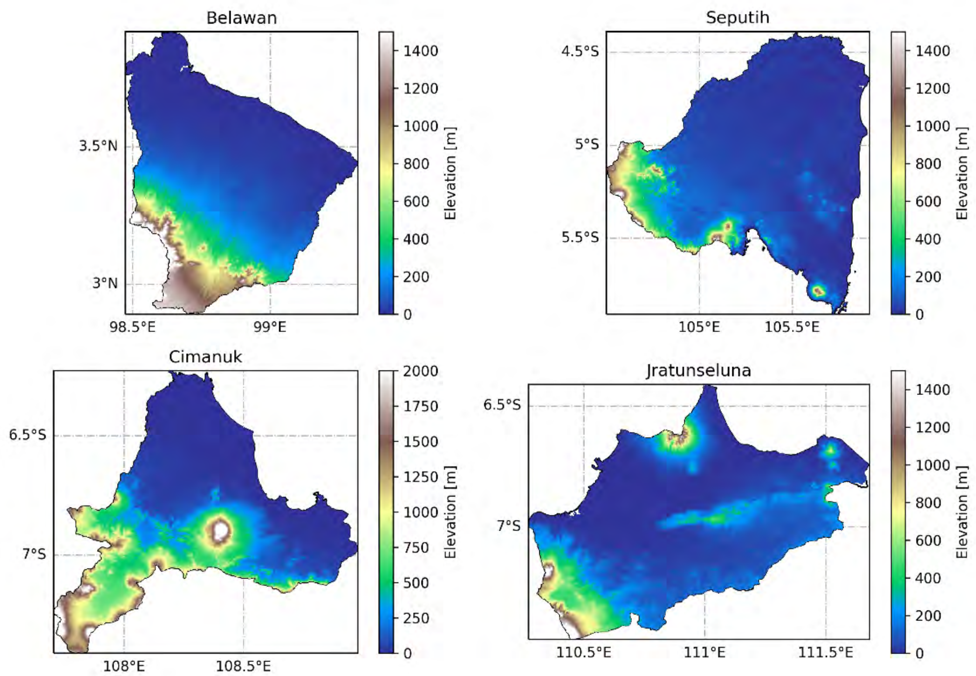

Figure 5: Digital Elevation Models (DEM) from HydroSHEDS for the pilot basins

47. HydroSHEDS also provides flow direction maps which indicate drainage direction throughout the basins. Both the DEM and flow direction maps are used to identify channels and route runoff through the basin.

48. All four catchments are coastal with large low-lying areas. In such areas sub basin delineation is challenging due to the relatively small elevation changes dictating flow direction relative to the precision of the input dataset. It was therefore decided to work only at basin scale for this project.

6.3 Precipitation

49. Remote sensing precipitation data was collected for the areas of interest for the years 2003 to 2014 in order to perform a preliminary analysis as well as the selection of the three historical years for final analysis. Precipitation data from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is shown in Figure 6.

50. Table 1 shows the identified dry, average and wet years for the basins. The years were selected within the period for which the full remote sensing dataset is available (2008-2014).

Table 1: Dry/Average/Wet years for the selected basins

	Belawan	Seputih	Cimanuk	Jratunseluna
Dry	2014	2009	2009	2009
Average	2012	2014	2014	2014
Wet	2009	2010	2010	2010

51.

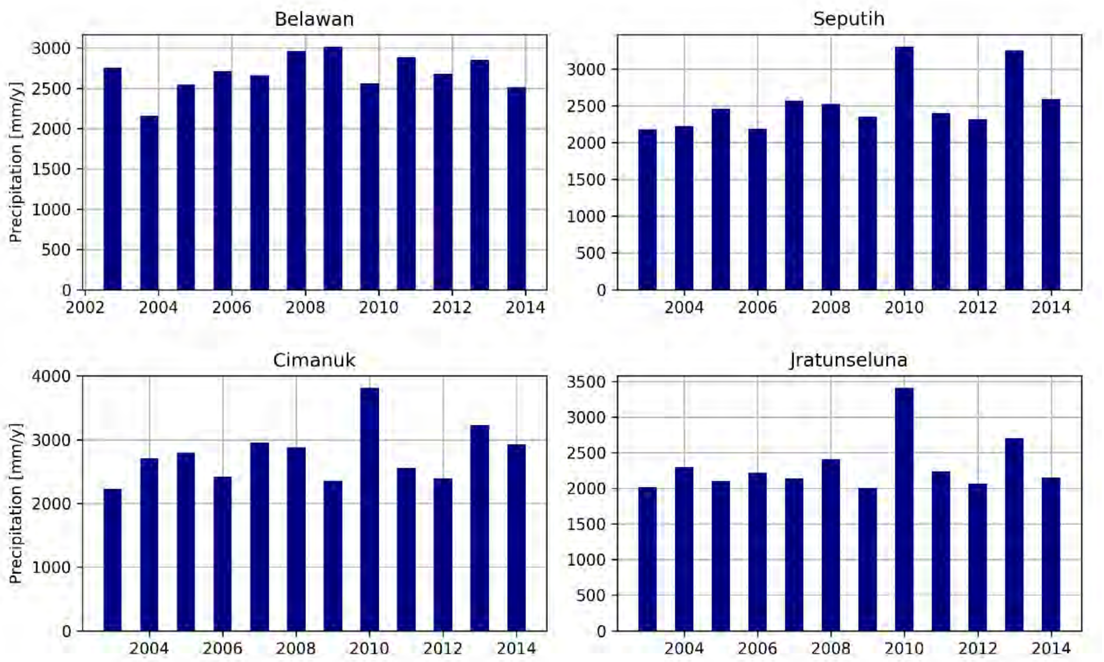

Figure 6: CHIRPS yearly precipitation for the 4 basins

52. The interannual variability is quite high in particular for the basins on Java with precipitation in the chosen dry years being 38% and 41% lower than that in the wet years for Cimanuk and Jratunseluna. For the basins of Belawan and Seputih on Sumatra, the decrease in precipitation for the dry years relative to the wet years is of 17% and 29% respectively.

53. Figure 7 shows the spatial variation across the basins as well as inter-annual variations in rainfall.

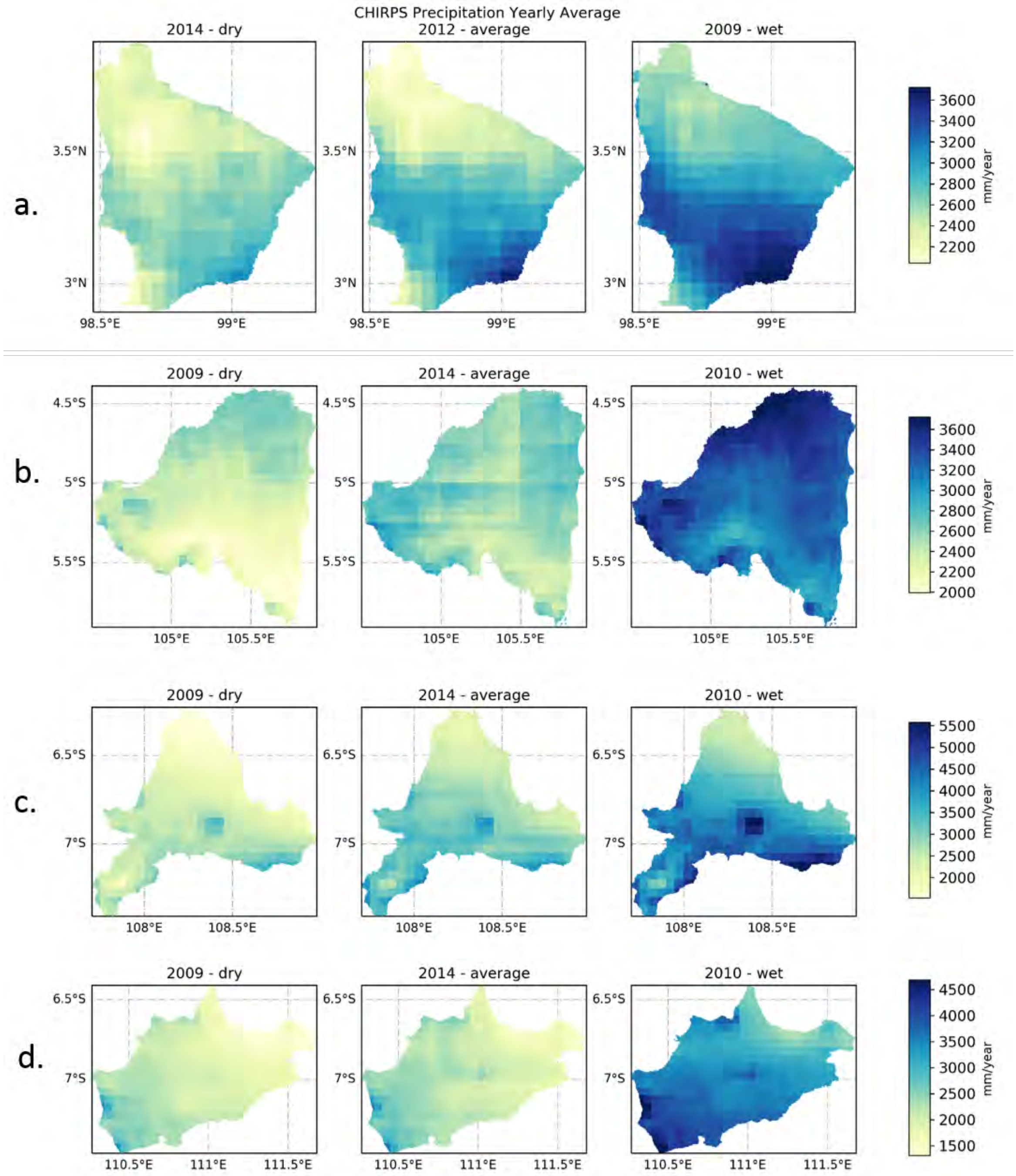

Figure 7: Rainfall from CHIRPS for Belawan(a), Seputih (b), Cimanuk (c) and Jratunseluna (d)

6.4 Actual Evapotranspiration (ET) and Water Yield

54. Monthly maps of actual evapotranspiration at 250 m resolution were computed for the period 2003-2014. This Actual ET dataset is the ensemble of seven global RS-based surface energy balance models (ETMonitor, GLEAM, CMRS-ET, SSEBop, ALEXI, SEBS, and MOD16) developed by IHE-Delft (Figure 8).

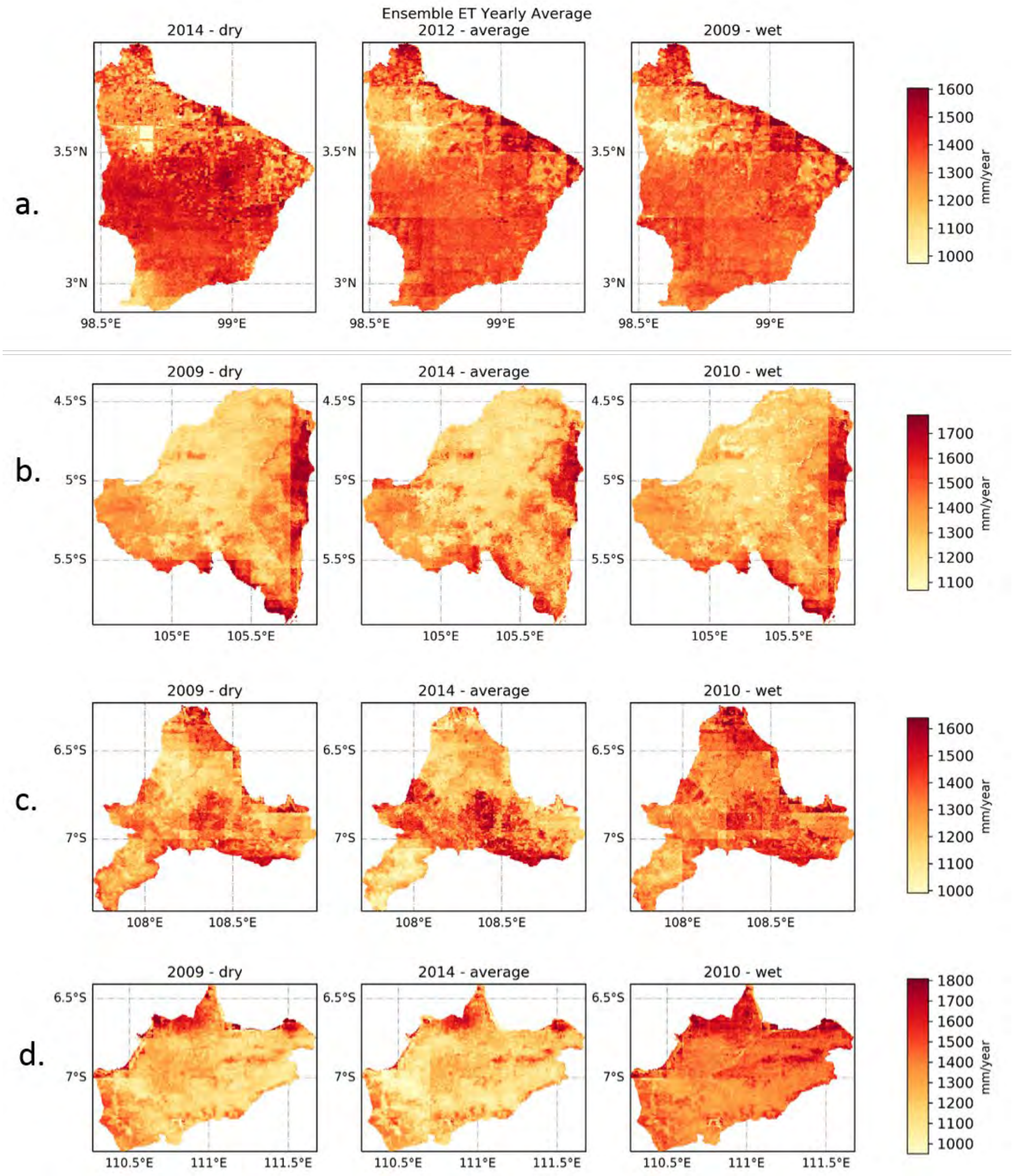

Figure 8: ET ensemble for Belawan(a), Seputih (b), Cimanuk (c) and Jratunseluna (d)

55. Water yield, which is defined as precipitation minus evaporation, can give a quick measure of water availability in a basin. Overall water balances in Indonesia are positive, indicating sufficient

water resources. However local water deficits may exist during the dry season. This pattern can also be observed in the pilot basins.

56. Figure 9 and Figure 10 show that while water yield remains positive on a yearly basis, the strong seasonal variability in rainfall leads to negative water yield values in the dry months in all basins except for Belawan.

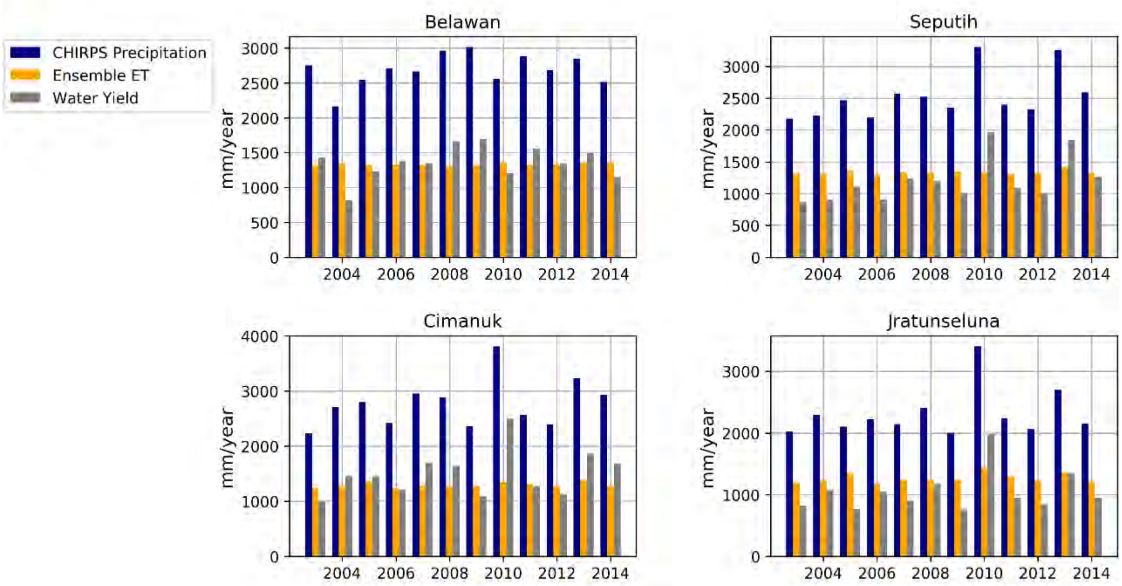

Figure 9: Yearly water yield

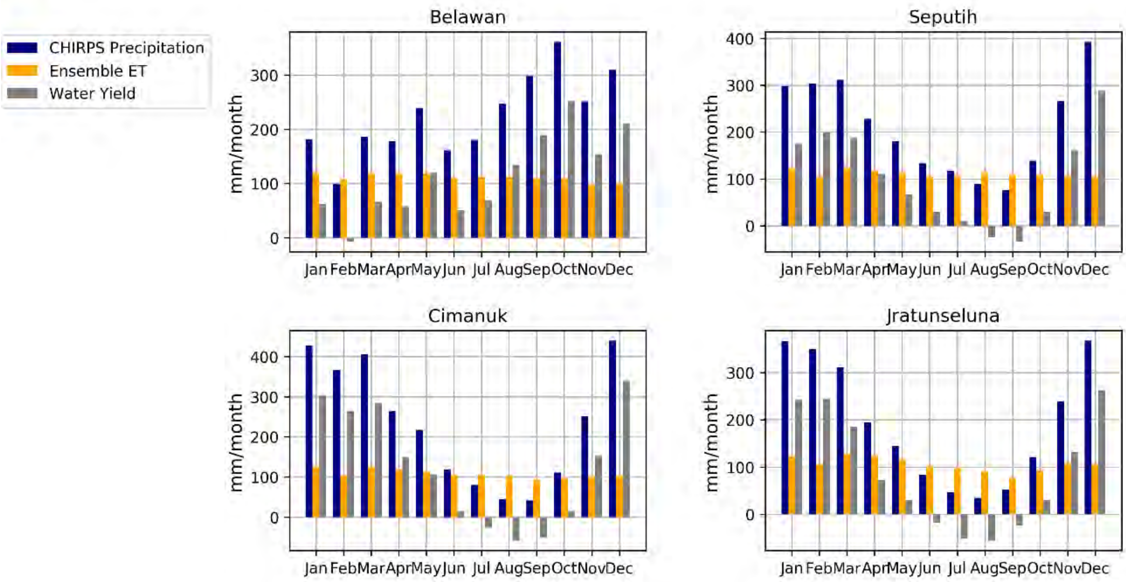

Figure 10: Seasonal water yield variability

57. Water yield also has a high spatial variability, Figure 11 shows spatial distribution of yearly water yield for the selected dry, average and wet years for the four basins.

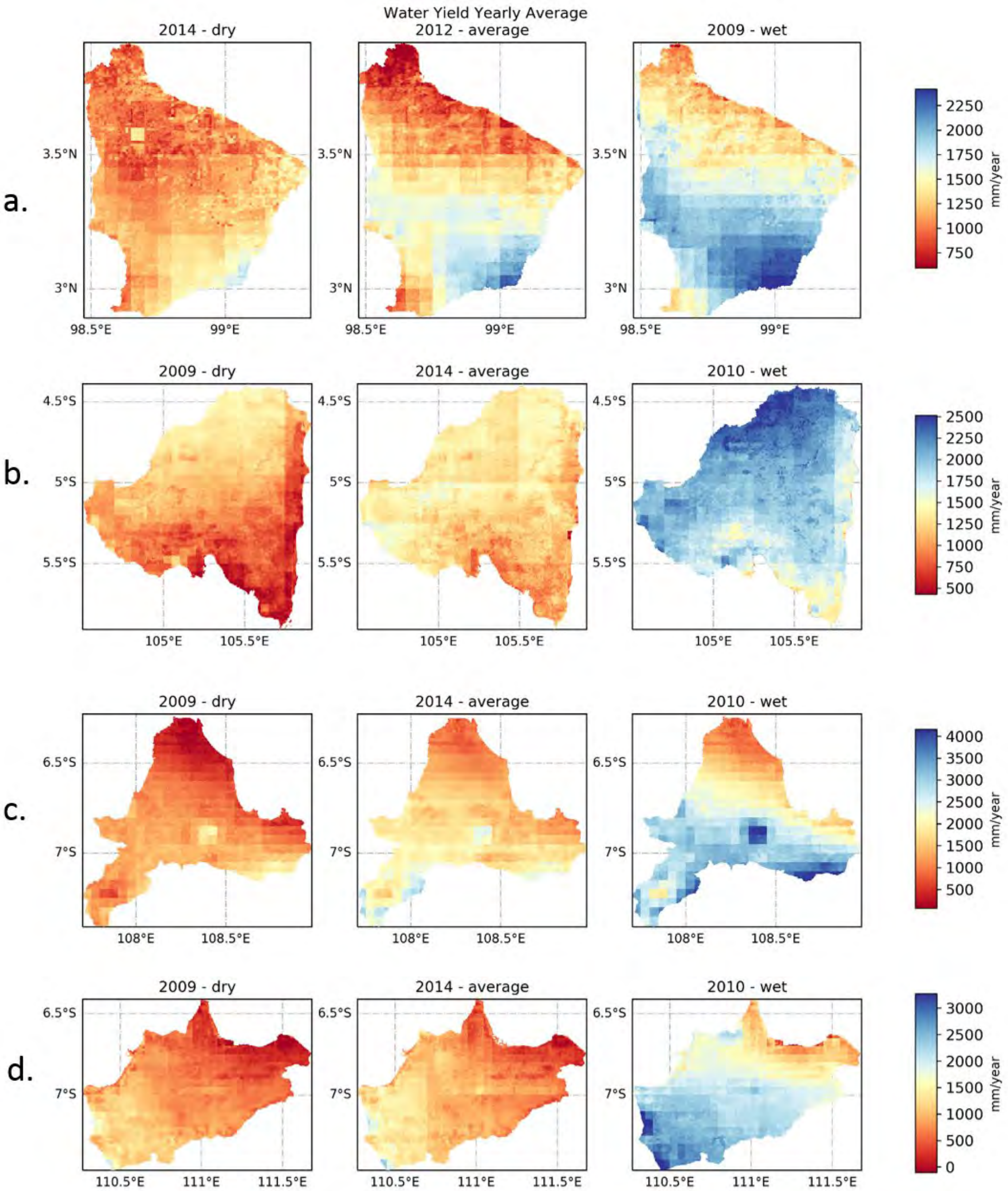

Figure 11: Yearly water yield for Belawan (a), Seputih (b), Cimanuk (c) and Jratunseluna (d)

6.5 Other datasets collected and processed

The other remote sensing datasets collected and used in the analysis as well as their sources are presented in Table 2.

Table 2: List of other datasets collected for the analysis

Data type	**Satellite/Database**	**Source/Further information**
Leaf Area Index (LAI)	MODIS (MOD15)	https://modis.gsfc.nasa.gov/data/dataprod/mod15.php
Soil Water Index (SWI)	ASCAT	http://www.ospo.noaa.gov/Products/atmosphere/ascat/
Net Dry Matter (NDM)	MODIS (MOD17)	https://modis.gsfc.nasa.gov/data/dataprod/mod17.php
Gross Primary Production (GPP)	MODIS (MOD17)	https://modis.gsfc.nasa.gov/data/dataprod/mod17.php
Weather data	GLDAS	https://ldas.gsfc.nasa.gov/gldas/
Total Water Storage variations (TS)	GRACE	http://ccar.colorado.edu/grace/
Soil Saturated Water Content (ϴsat)	HiHydroSoil	Future Water

6.6 In-Situ Data: Surface Water

58. PUSAIR (research center of water resources in Indonesia) have provided the WA+ team with discharge station data for the 4 pilot basins. The location of these stations is shown in Figure 12.

59. The stations were used as a validation dataset in order to check the order of magnitude of the flows estimated with the WA+ method. Perfect matches are not expected as many reservoirs and tanks regulate discharge in Indonesia, and these were not represented in our study.

60. Some of the stations could not be used due to lack of overlapping measurement dates with our study.

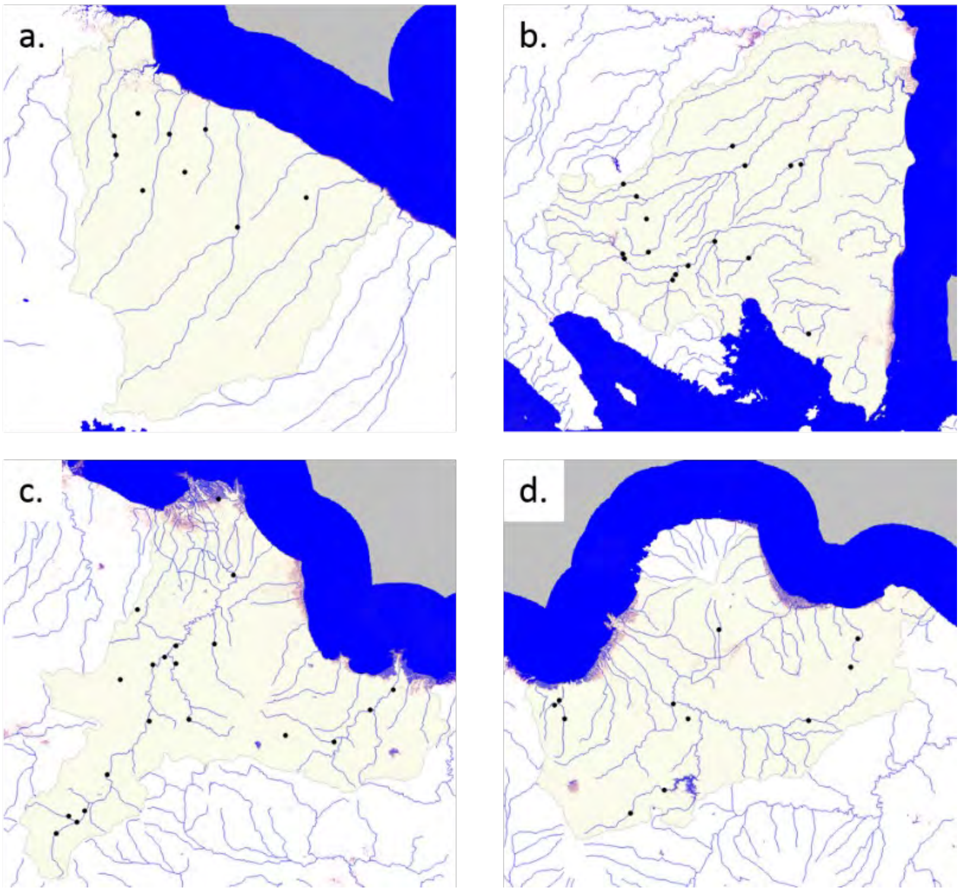

Figure 12: location of in situ gaging stations for a. Belawan, b. Seputih, c. Cimanuk and d. Jratunseluna. Background image is percent water occurrence from JRC (https://global-surface-water.appspot.com/)

7 Summary of the Water Accounts

61. The Water Accounting Plus tools and models were applied in each basin. The following section will present the main results for each river basin. For all basins, the tables present the dry, average, and wet year results in that order in the tables.

62. The full set of monthly and yearly accounting sheets can be found at www.wateraccounting.org

7.1 Cimanuk Cisanggarung River Basin

7.1.1 Basin scale water availability

63. On a yearly basis, the Cimanuk river basin was found to have sufficient water resources, with water yields remaining positive (see section 6.4, Figure 9). The relative magnitudes of the inflows and outflows of the basin are presented in Figure 13.

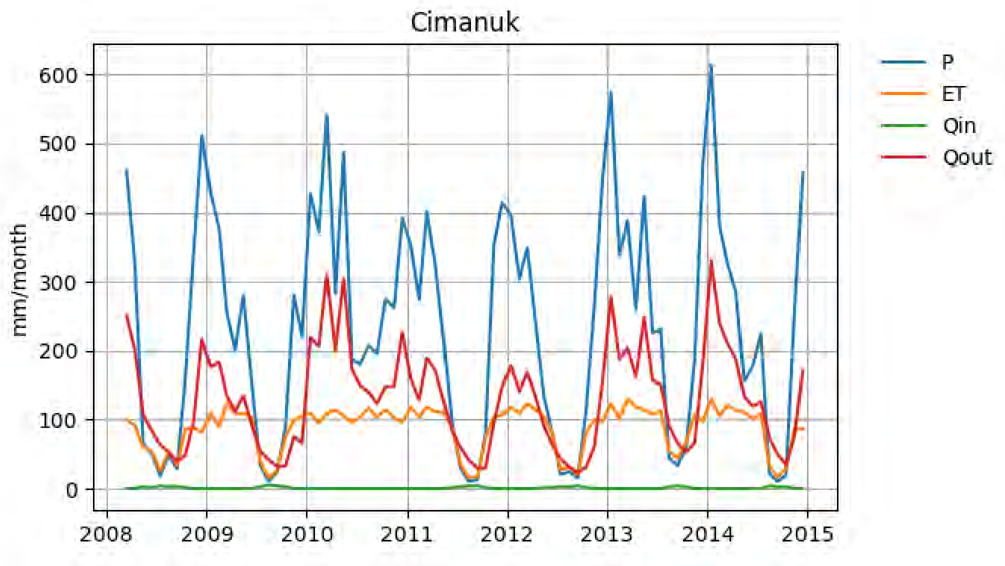

Figure 13: Inflows and Outflows, Cimanuk

64. Water availability is however highly seasonal (Figure 13) with negative basin-averaged water yields for the months of July through September (see section 6.4, Figure 10). Negative water yields can occur naturally, as water in natural storages evaporates during dryer months, but can also point to a reliance on ground and surface water storages during dry months for irrigation purposes.

65. For the average and low precipitation years, the analysis showed a small decrease in total storage (positive Delta S in Table 3) in the basin, while the wet year shows a small increase (negative Delta S in Table 3). These changes in storage represent only between 1.8 % and 3.1 % of the precipitation and are therefore within the expected error of the input data and no major conclusions can be drawn based on the absolute values of the changes in storage. However their small values and the stable multiannual storage indicate a balance between the water inputs and outputs for the basin.

66. In practical terms this means the study did not reveal an issue of overexploitation of water resources in the basin under current conditions.

Table 3: Summary of in and outflows, Cimanuk.

	Precipitation	ET	Delta S	Qin	Qout	Qin	Qout
YEAR	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*m3/s*	*m3/s*
2009	2354	1274	42	14	1137	3.6	277.93
2014	2929	1269	82	8	1751	2.15	427.95
2010	3810	1342	-119	1	2349	0.4	574.05

67. The Cimanuk Cisanggarung Basin is a headwater basin and does not receive any inflows from other basins, the small Qin value in Table 3 is due to the consumption of sea water in coastal fishponds.

68. Total storage variations in the basin were found to be in agreement with those observed by the Gravity Recovery and Climate Experiment (GRACE, Figure 14).

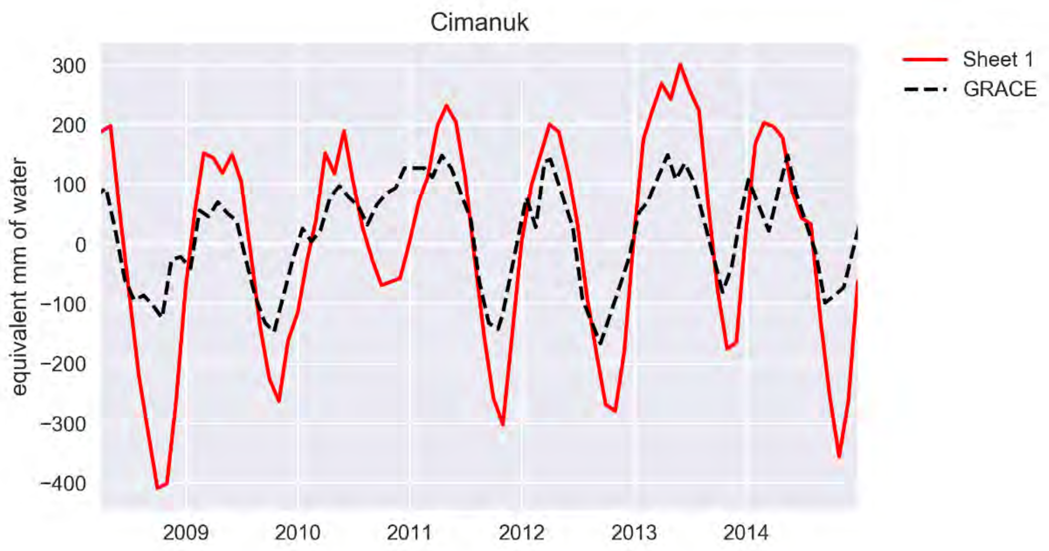

Figure 14: Total storage relative to arbitrary reference point, Cimanuk

7.1.2 Water Consumption (ET) & Agricultural Production

69. Relative to precipitation, evapotranspiration (ET) has a lower inter-annual variability. The amount of water consumed through ET varies between 35 % of precipitation for the wettest year and 54 % of precipitation for the driest year analyzed.

70. While ET is higher for the wet year (2010), the portion of ET going to transpiration (T) and therefore directly linked to plant growth decreases for the wettest year (2010, see Table 4). This can happen in humid conditions.

71. The drop in transpiration and relative increase of evaporation (E) and interception (I) explains the drop in percentage of beneficial ET from above 60% for the average and dry years to below 50% for the wet year (Table 4). This is because all transpiration is considered a beneficial water consumption as it represents a use directly contributing to pant growth and therefore the

agricultural and economic sectors. Many other evaporative consumptions (for example evaporation from the soil) are considered non-beneficial.

Table 4: Summary of Sheet2, Cimanuk

	ET	**E**	**T**	**I**	**Beneficial**		**Non Beneficial**	
YEAR	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*% of ET*	*mm/yr*	*% of ET*
2009	1274	196	881	196	836	65	437	34
2014	1268	213	846	209	809	63	459	36
2010	1343	311	701	329	667	49	676	50

72. Due to persistent cloud cover over part of the year for the study area, the crop growing seasons could not be estimated using remote sensing and standard values from the FAO for the island of Java were used. Irrigated rice was assumed to have two growing seasons: from October to April and May to September, and rainfed rice a single growing season from October to April.

73. Crop water consumption is the water consumed through ET over cropped areas during the growing season. The average values for irrigated and rainfed areas are summarized in (Table 5).

Table 5: Crop Water Consumption, Cimanuk

	Crop Water Consumption	
	Rainfed	**Irrigated**
YEAR	*mm/yr*	*mm/yr*
2009	336	496
2014	244	398
2010	343	513

74. A useful measure of cropped areas is the land productivity expressed in kg/ha/year. Rice is the major crop grown in Cimanuk. Our study found average land productivities between 1905 and 3620 kg/ha/year for rainfed rice and between 5245 and 7269 kg/ha/year for irrigated rice (Table 6).

75. It should be noted that this study was carried out using a single land use map and therefore any changes over time in cropped or irrigated areas are not reflected in the results presented here.

76. Water productivity also goes up for irrigated crops, with values between .55 kg/m^3 and .73 kg/m^3 for irrigated crops vs. values between .29 kg/m^3 and .57 kg/m^3 for rainfed crops (Table 6). These values are below the global average of 1.1 kg/m^3 for paddy rice.

77. The lower water productivity observed in the wettest year is a consequence of the same process leading to a lower proportion of transpiration in humid conditions.

Table 6: Land and Water Productivity, Cimanuk

		Land Productivity		Water Productivity	
		Rainfed	Irrigated	Rainfed	Irrigated
YEAR	Crop Type	*kg/ha/year*	*kg/ha/year*	*kg/m3*	*kg/m3*
2009	Rice	3620	7269	0.56	0.73
	Feed crops	7786		1.15	
	Other crops	6236	6236	0.47	0.47
2014	Rice	1905	5245	0.57	0.72
	Feed crops	4086		1.15	
	Other crops	6004	6004	0.43	0.43
2010	Cereals	3471	5947	0.53	0.55
	Feed crops	7383		1.07	
	Other crops	4404	4404	0.32	0.32

78. The constant productivities for non-cereal crops suggest a potential classification error, and it is likely that all or most non-cereals in the basin are rainfed. The area classified as irrigated other crops only represents 3% of the total area of the basin.

7.1.3 Water Supply

79. The total withdrawals in the basin were estimated using the WaterPix model. The model estimates additional supply based on the concept of green and blue ET: green ET is the evapotranspiration which can be explained by rainfall alone and can be computed using an empirical equation. If total measured ET is found to be higher than this value, we can assume that an additional source of water had to be added to generate the ET amounts measured, and from this calculate supply.

80. Withdrawals were found to vary dramatically between the wet and dry years analyzed (see Table 7). The majority of the manmade withdrawals are used for irrigation purposes with these accounting for between 67 and 70% of gross withdrawals. Residential water supply is the second largest user, accounting for 17 to 18% of the total manmade water supply. The residential water demand was estimated based on population density maps.

81. In Table 7, “other” consumed water refers to water not consumed through ET blue but nonetheless made unavailable to downstream users due to for example pollution.

Table 7: Basin wide withdrawals, Cimanuk

	Manmade					Natural		
	Gross Withdr.	Consumed			Non Cons.	Gross Withdr.	Consumed	Non Cons.
		ETb	ETb/Supply	Other			ETb	
YEAR	*mm/yr*	*mm/yr*	*%*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*
2009	698	263	37	189	245	307	289	17
2014	546	225	41	144	176	259	256	2
2010	327	58	17	111	157	106	105	1

82. The fraction of the manmade supply consumed in the evaporative process varies between 17% and 41% for the wet, and average years respectively (Table 7). Note that blue ET (ETb in Table 5) is only the portion of total evapotranspiration that can be attributed to water supply, whether it be from manmade (f.ex. irrigation) or natural extractions (f.ex. groundwater used by deep rooting trees).

83. The low value of supply consumption through ET of 17% for the year 2010 suggests that while our study showed a reduction in irrigation amounts for the wet year, these amounts could have been further reduced as far as the benefits to crop growth are concerned.

84. It should however be noted that the excess non-consumed water due to this low consumption can also be beneficial to the basin in particular through increased infiltration amounts contributing to both the recharge of groundwater and an increase in baseflow.

7.1.4 Surface Water & Discharge

85. The amount of runoff generated was estimated using the WaterPix model. The spatial distribution of runoff generation is shown in Figure 15.

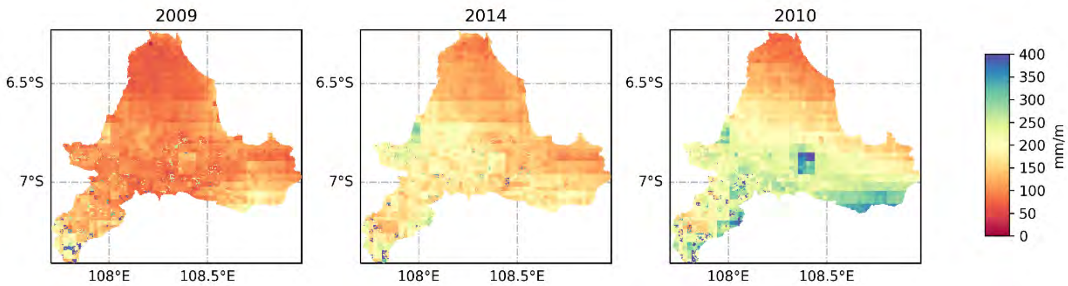

Figure 15: Average monthly runoff, Cimanuk

86. Most of the runoff is generated in MLU and MWU land use classes (see Table 8) which cover 39 and 50% of the basin area respectively.

Table 8: Generated runoff per landuse category, Cimanuk

	Runoff [km3/yr]			Runoff [mm/yr]		
	2009	**2014**	**2010**	**2009**	**2014**	**2010**
UTILIZED	0.29	0.39	0.58	1580	2075	3116
PROTECTED	0.48	0.72	1.04	1400	2108	3043
MANAGED	5.43	7.38	8.81	1346	1831	2187
MODIFIED	3.92	6.1	8.35	1246	1940	2652

87. Discharge was estimated by routing the runoff using the SurfWat tool. The SurfWat tool also operates the removal of supply from surface water from the accumulated flows.

88. The reservoir simulation module of the tool is still under development, and in the absence of reservoir release data, their operation was not included in the study. This can explain that while there is general agreement in order of magnitude and timing of discharge (Figure 16), the high flows simulated in SurfWat tend to be higher than those observed, and the dry season flows can be seen to sometimes drop to 0 where reservoir releases would in practice take up some of the water demand.

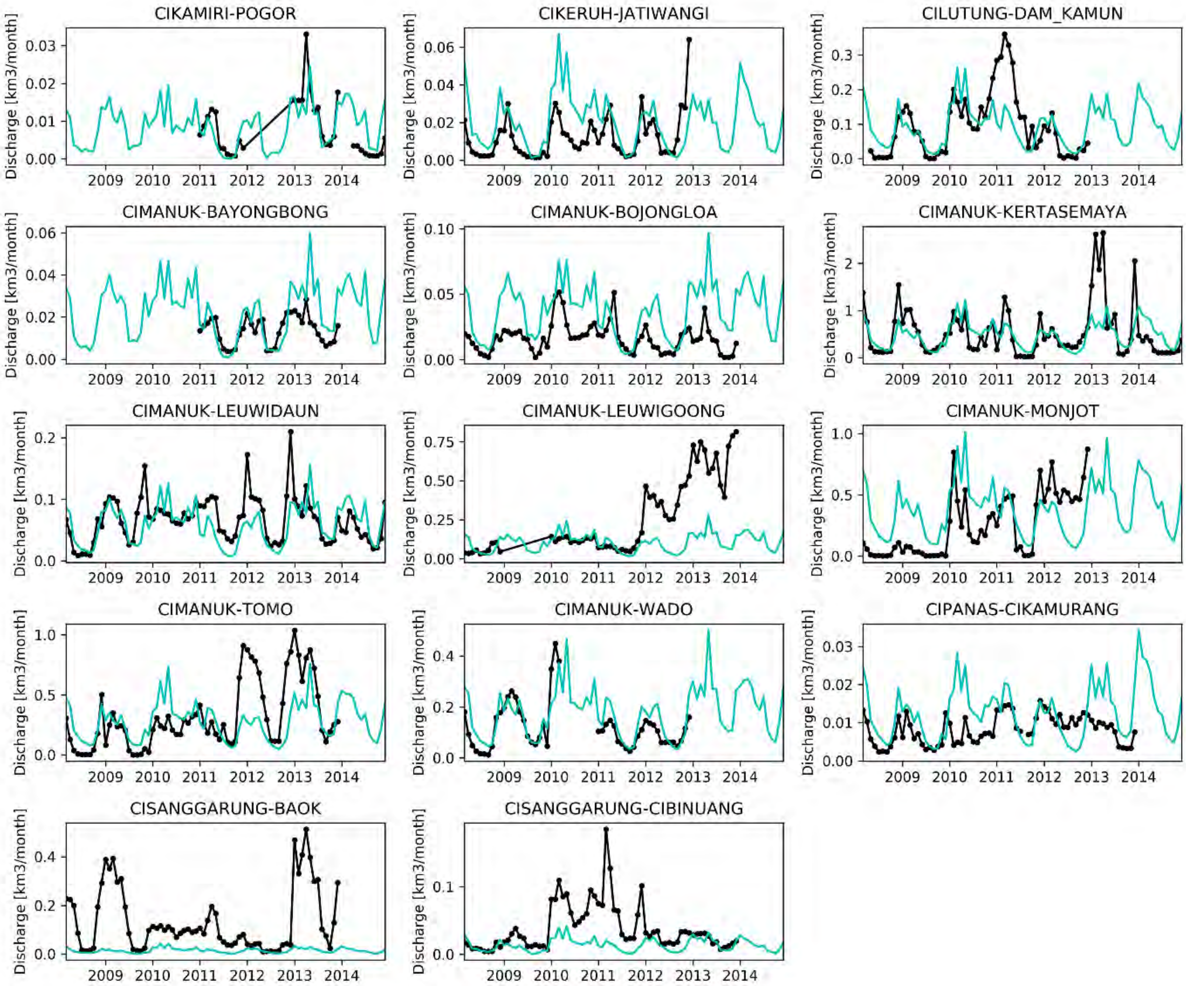

Figure 16: Estimated (cyan) and in-situ (black) discharge, Cimanuk

89. Figure 17 shows that each year, utilizable outflow in the basin falls to 0 during the dry season, except in the wettest year (2010).

90. This indicates that any further water resource exploitation in the basin will need to rely on storages, surface or groundwater to avoid tapping into the committed flows. These committed flows are estimated environmental water requirements.

91. Considering the magnitude of utilizable outflows during the wet season, surface water storages could help spread out available water throughout the year.

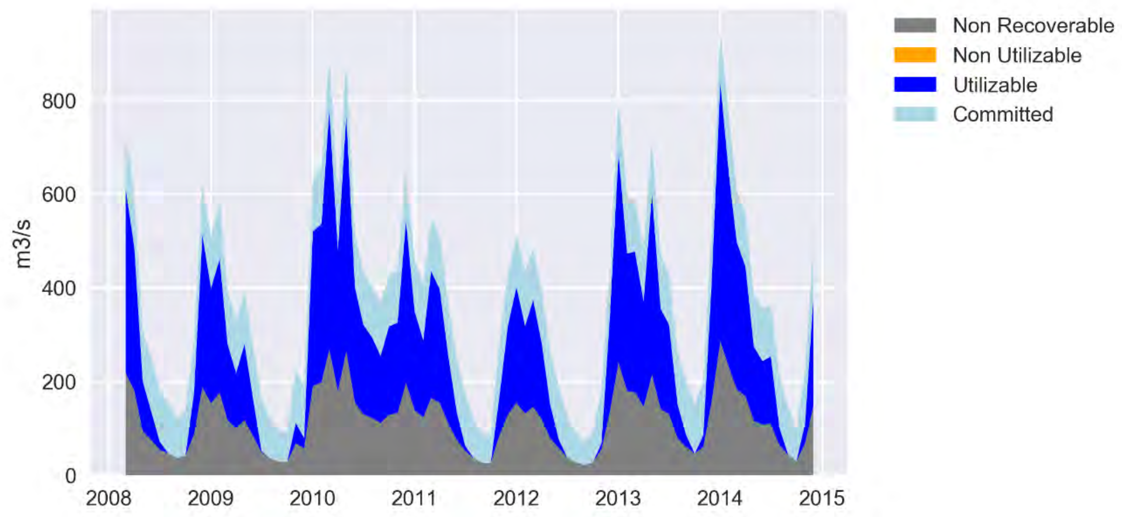

Figure 17: Utilizable and other outflows, Cimanuk

7.2 Jratun Seluna River Basin

7.2.1 Basin scale water availability

92. On a yearly basis, the Jratunseluna river basin was found to have sufficient water resources, with water yields remaining positive (see section 6.4, Figure 9). The relative magnitudes of the inflows and outflows of the basin are presented in Figure 18.

93. Water availability is however highly seasonal (Figure 18) with negative basin-averaged water yields for the months of June through September (see section 6.4, Figure 10). Precipitation is concentrated in the areas of higher elevation in the north, south west and, to a lesser extent, in the west (Figure 6).

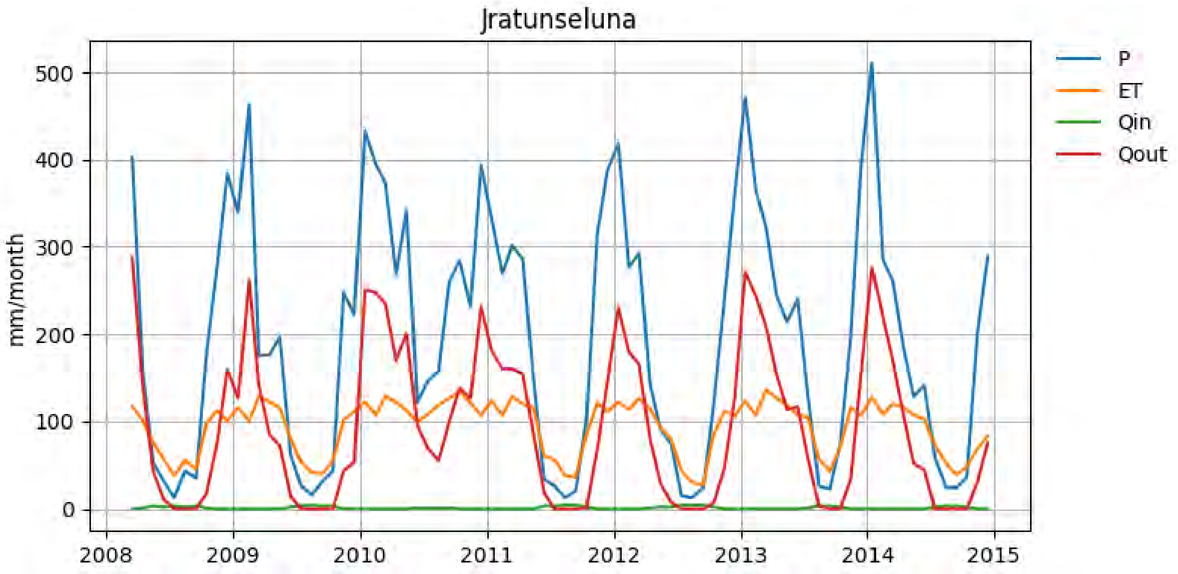

Figure 18: Inflows and Outflows, Jratunseluna

94. For the average and low precipitation years, the analysis showed a small decrease in total storage (positive Delta S in Table 9) in the basin, while the wet year shows a small increase (negative Delta S in Table 9). These changes in storage represent only between 1.2 % and 1.5 % of the precipitation and are therefore within the expected error of the input data and no major conclusions can be drawn based on the absolute values of the changes in storage. However their small values and the stable multiannual storage indicate a balance between the water inputs and outputs for the basin.

Table 9: Summary of in and outflows, Jratunseluna

	Precipitation	**ET**	**Delta S**	**Qin**	**Qout**	**Qin**	**Qout**
YEAR	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*m3/s*	*m3/s*
2009	2001	1251	31	16	798	4.96	234.1
2014	2148	1207	25	10	978	3.22	286.72
2010	3408	1440	-51	4	1920	1.45	563.09

95. In practical terms this means the study did not reveal an issue of overexploitation of water resources in the basin under current conditions. This is consistent with the total change in water storage as estimated by the Gravity Recovery and Climate Experiment (GRACE, see Figure 19).

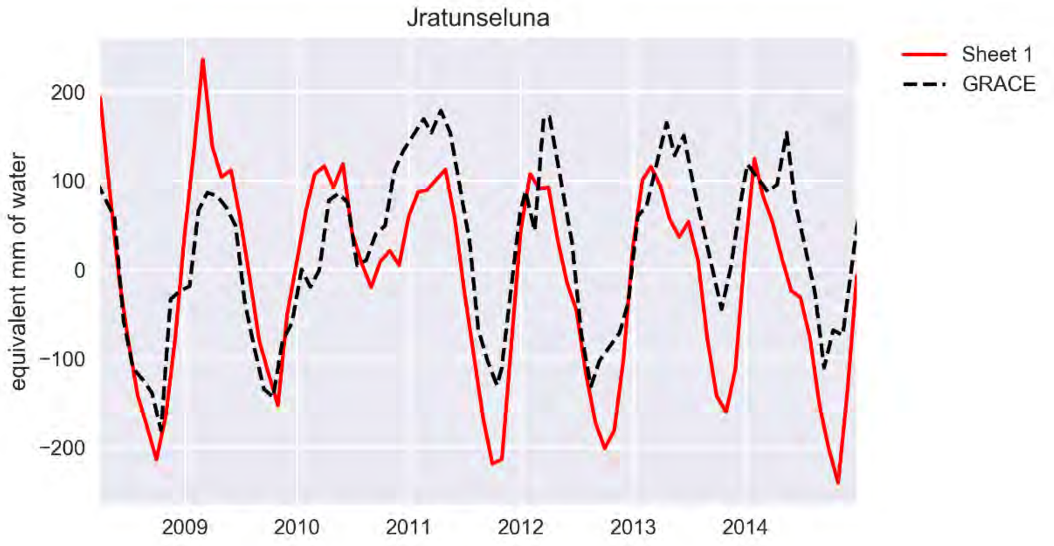

Figure 19: Total water storage relative to arbitrary reference, Jratunseluna

96. This is also reflected in the long-term stability of groundwater storage in the basin (Figure 19).

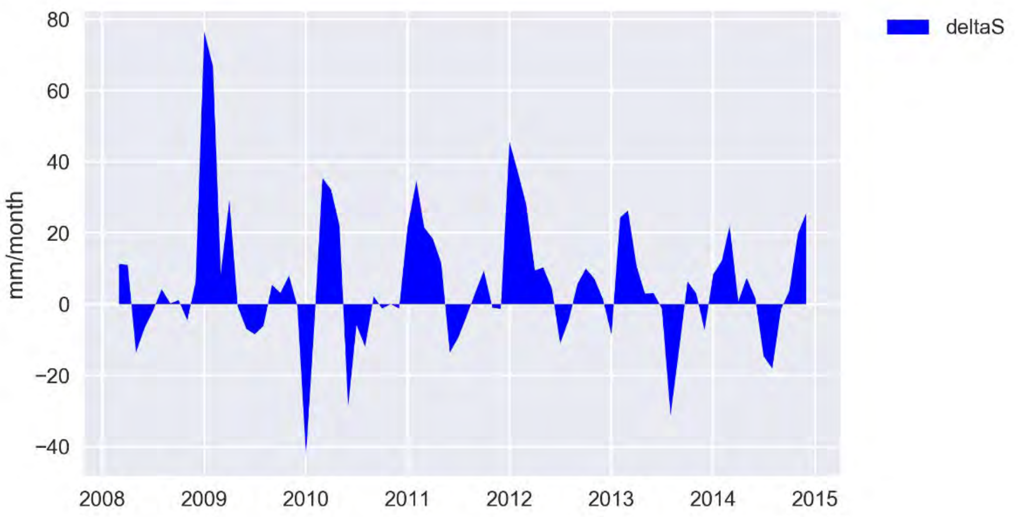

Figure 20: Groundwater storage variations, Jratunseluna

97. The Jratunseluna River Basin is a headwater basin and does not receive any inflows from other basins, the small Qin value in Table 3 is due to the consumption of sea water in coastal fishponds.

7.2.2 Water Consumption (ET) & Agricultural Production

98. Relative to precipitation, evapotranspiration (ET) has a lower inter-annual variability. The amount of water consumed through ET varies between 42 % of precipitation for the wettest year and 63 % of precipitation for the driest year analyzed.

99. The percentage of beneficial ET remains high (between 61 and 69% of total ET).

Table 10: Summary of evaporative consumption, Jratunseluna

	ET	E	T	I	Beneficial		Non Beneficial	
YEAR	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*% of ET*	*mm/yr*	*% of ET*
2009	1248	208	895	143	856	68	391	31
2014	1203	179	868	155	835	69	368	30
2010	1437	263	918	254	877	61	559	38

100. Due to persistent cloud cover over part of the year for the study area, the crop growing seasons could not be estimated using remote sensing and standard values from the FAO for the island of Java were used. Irrigated rice was assumed to have two growing seasons: from October to April and May to September, and rainfed rice a single growing season from October to April.

101. Crop water consumption is the water consumed through ET over cropped areas during the growing season. The average values for irrigated and rainfed areas are summarized in (Table 11).

Table 11: Crop Water Consumption, Jratunseluna

	Crop Water Consumption	
	Rainfed	**Irrigated**
YEAR	*mm/yr*	*mm/yr*
2009	353	362
2014	240	296
2010	384	407

102. A useful measure of cropped areas is the land productivity expressed in kg/ha/year. Rice is the major crop grown in Cimanuk, the land average land productivities were found to be between 1217 and 2524 kg/ha/year for rainfed rice and between 4822 and 6003 kg/ha/year for irrigated rice (Table 12).

103. It should be noted that this study was carried out using a single land use map and therefore any changes over time in cropped or irrigated areas are not reflected in the results presented here.

104. Water productivity also goes up for irrigated crops, with values between .49 kg/m^3 and .68 kg/m^3 for irrigated crops vs. values between .35 kg/m^3 and .38 kg/m^3 for rainfed crops (Table 12). These values are below the global average of 1.1 kg/m^3 for paddy rice.

Table 12: Land and Water Productivity, Jratunseluna

		Land Productivity		Water Productivity	
		Rainfed	**Irrigated**	**Rainfed**	**Irrigated**
YEAR	**Crop Type**	*kg/ha/year*	*kg/ha/year*	*kg/m3*	*kg/m3*
2009	**Rice**	2524	6003	0.38	0.61
	Feed crops	5113		0.7	
	Other crops	3272	3272	0.27	0.27
2014	**Rice**	1217	4822	0.37	0.68
	Feed crops	2547		0.69	

	Other crops	3428	3428	0.29	0.29
2010	**Rice**	2404	5453	0.35	0.49
	Feed crops	4638		0.62	
	Other crops	3174	3174	0.22	0.22

7.2.3 Water Supply

105. The total withdrawals in the basin were estimated using the WaterPix model. The model estimates additional supply based on the concept of green and blue ET: green ET is the evapotranspiration which can be explained by rainfall alone and can be computed using an empirical equation. If total measured ET is found to be higher than this value, we can assume that an additional source of water had to be added to generate the ET amounts measured, and from this calculate supply.

106. Withdrawals in the basin were found to vary dramatically between the wet and dry years analyzed (see Table 13). The majority of the manmade withdrawals are used for irrigation purposes with these accounting for between 50 and 69% of gross manmade withdrawals. Residential water supply is the second largest user, accounting for 17 to 29% of the total manmade water supply. The residential water demand was estimated based on population density maps.

Table 13: Basin wide withdrawals, Jratunseluna

	Manmade					**Natural**		
	Gross Withdr.	**Consumed**			**Non Cons.**	**Gross Withdr.**	**Consumed**	**Non Cons.**
		ETb	**ETb/Supply**	**Other**			**ETb**	
YEAR	*mm/yr*	*mm/yr*	*%*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*
2009	368	174	47	117	76	224	210	13
2014	372	159	42	109	103	184	174	10
2010	152	31	20	69	50	44	39	5

107. The fraction of the manmade supply consumed in the evaporative process varies between 20% and 47% for the wet, and dry years respectively (Table 13). Note that blue ET (ETb) is only the portion of total evapotranspiration that can be attributed to water supply, whether it be from manmade (f.ex. irrigation) or natural extractions (f.ex. groundwater used by deep rooting trees).

108. The low value of supply consumption through ET of 20% for the year 2010 suggests that while our study showed a reduction in irrigation amounts for the wet year, these amounts could have been further reduced as far as the benefits to crop growth are concerned.

109. It should however be noted that the excess non-consumed water due to this low consumption can also be beneficial to the basin in particular through increased infiltration amounts contributing to both the recharge of groundwater and an increase in baseflow.

7.2.4 Surface Water & Discharge

110. The amount of runoff generated was estimated using the WaterPix model. The spatial distribution of runoff generation is shown in Figure 20.

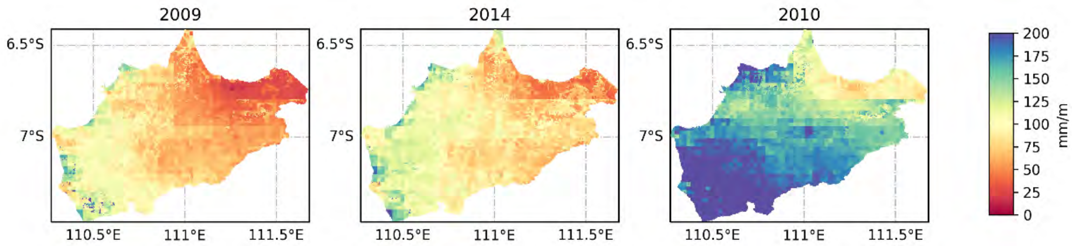

Figure 21: Average monthly runoff, Jratunseluna

111. Most of the runoff is generated in MLU and MWU land use classes (see Table 14) which cover 46 and 51% of the basin area respectively.

Table 14: Runoff generation, Jratunseluna

	Runoff [km3/yr]			Runoff [mm/yr]		
	2009	**2014**	**2010**	**2009**	**2014**	**2010**
UTILIZED	0.18	0.2	0.4	1139	1244	2445
PROTECTED	0.04	0.05	0.09	1642	2013	3715
MANAGED	4.55	5.53	9.42	954	1160	1977
MODIFIED	3.68	4.43	8.42	856	1030	1959

112. Discharge was estimated by routing the runoff using the SurfWat tool, which is a flow accumulation model developed at IHE Delft. The reservoir simulation module of the tool is still under development, and in the absence of reservoir release data, they were not included in the study. This can explain that while there is general agreement in order of magnitude and timing of discharge (Figure 21), the high flows simulated in SurfWat tend to be higer than those observed, and the dry season flows can be seen to sometimes drop to 0 where reservoir releases would in practice take up some of the water demand.

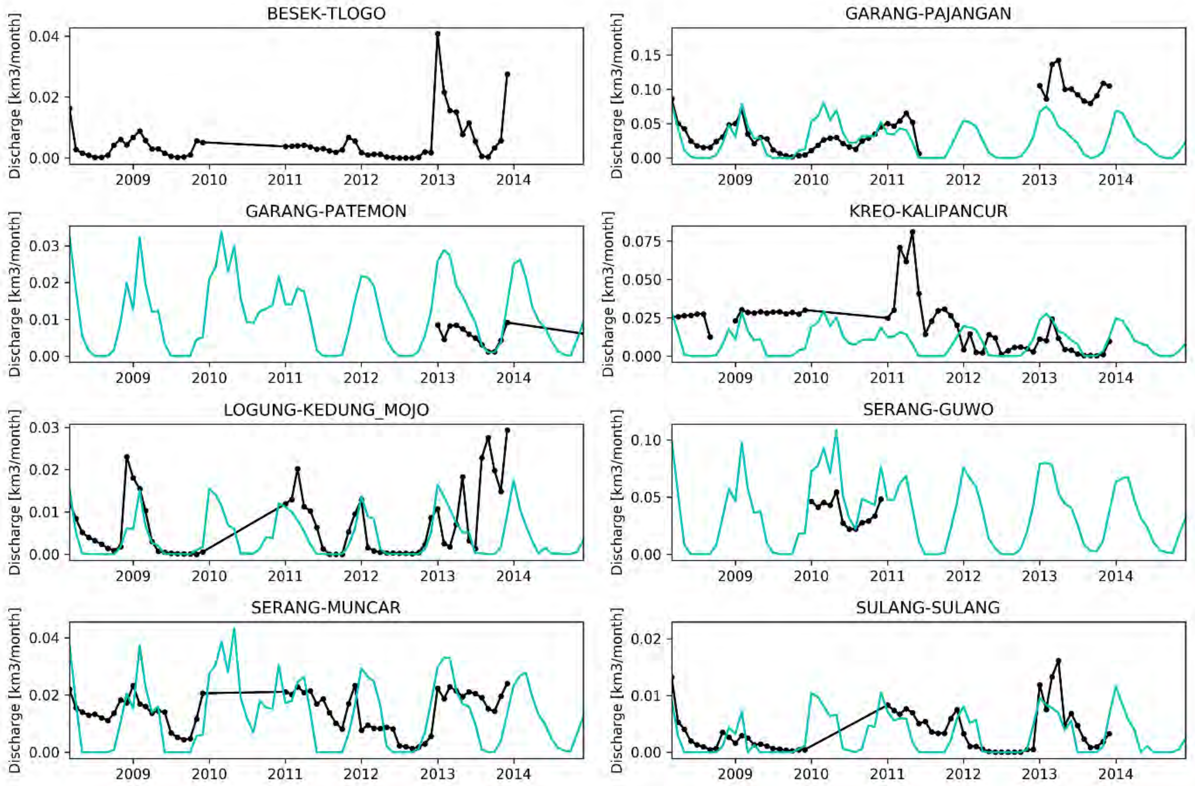

Figure 22: Estimated (cyan) vs. in situ (black) discharge, Jratunseluna

113. Figure 22 shows that each year, outflows in the basin falls to 0 during the dry season except during the wet year (2010). This indicates that any further water resource exploitation in the basin will need to rely on storages, surface or groundwater. Surface water storages could help spread out available water throughout the year. However, a large proportion of theses outflows have been classified as non-recoverable, or polluted, in our study.

114. This assessment is based on a global map of water pollution (Mekonnen and Hoekstra, 2017. Accessible at: http://waterfootprint.org/media/downloads/Mekonnen-Hoekstra-2017.pdf). In order for these flows to be used (or reused as they are typically return flows from irrigation) a careful assessment of water quality and management of agricultural practices should be undertaken.

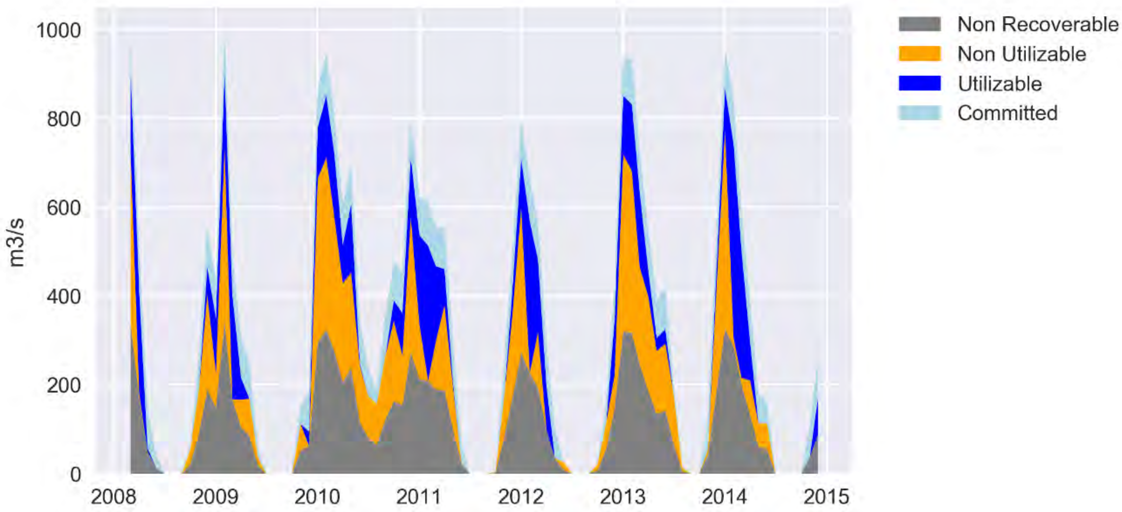

Figure 23: Utilizable and other outflows, Jratunseluna

115. Scenarios from climate models predict that precipitation will increase in wet months and decrease in dry months over Indonesia, thereby further increasing the current seasonal water availability disparities (see for example http://sdwebx.worldbank.org/climateportal/).

116. The coastal location, coupled with sea level rise means that any reliance on groundwater supplies runs the risk of salt water intrusion to the aquifers and should be very carefully considered.

7.3 Deli-Percut-Belawan River Basin

7.3.1 Basin scale water availability

117. On a yearly basis, the Belawan river basin was found to have sufficient water resources, with water yields remaining positive (see section 6.4, Figure 9). The relative magnitudes of the inflows and outflows of the basin are presented in Figure 18.

118. Water availability is however seasonal (Figure 23) though not to as high of a degree as the other river basins analyzed. Belawan is the only of the pilot basins for which the monthly water yield remains positive throughout the year on a basin level, with only a very slightly negative value on average in March (see section 6.4, Figure 10). This is due to the precipitation not seeing as drastic of a reduction as the other basins during the dry season (Figure 23).

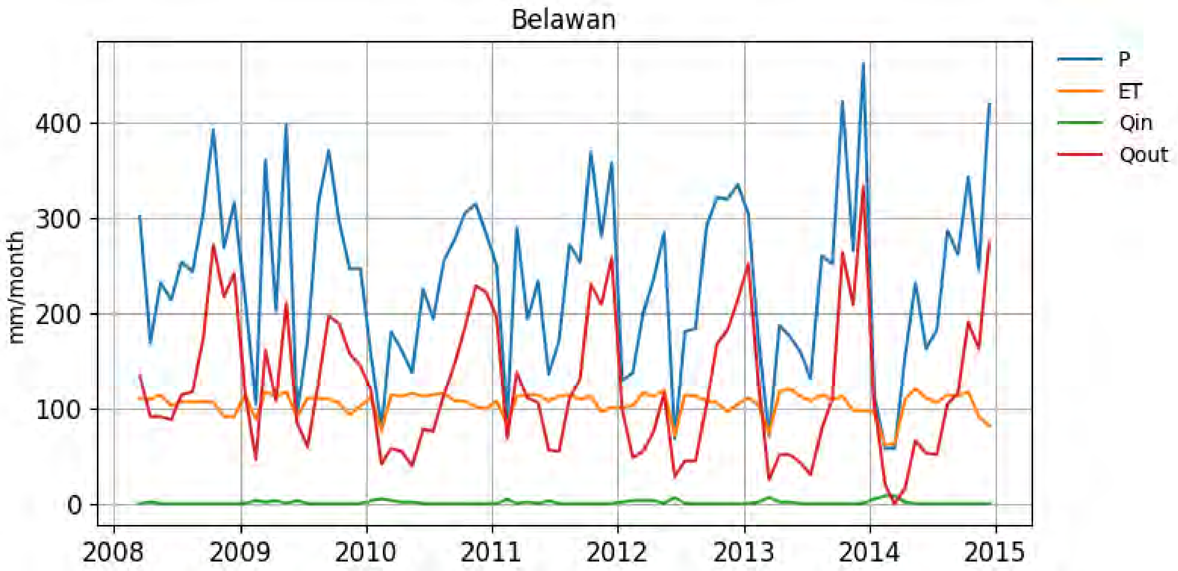

Figure 24: Inflows and Outflows, Belawan

For all years, our study shows small increase in total storage (negative Delta S inTable 15). These changes in storage represent between 1 % and 7 % of the precipitation and are therefore within the expected error of the input data and no major conclusions can be drawn based on the absolute values of the changes in storage. However their small values and the stable multiannual storage indicate a balance between the water inputs and outputs for the basin.

In practical terms this means the study did not reveal an issue of overexploitation of water resources in the basin under current conditions.

Table 15: Summary of in and outflows, Belawan

	Precipitation	**ET**	**Delta S**	**Qin**	**Qout**	**Qin**	**Qout**
YEAR	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*m3/s*	*m3/s*
2014	2515	1358	-24	23	1156	4.57	221.46
2012	2685	1332	-195	18	1176	3.61	224.69
2009	3020	1320	-116	10	1594	2	305.3

119. Belawan was the only of the pilot basins for which the total water storage change calculated as a residual of the inputs and outputs to the basin did not show a good fit with the observed data from the Gravity Recovery and Climate Experiment (GRACE, see Figure 25). Additional validation data, in particular precipitation, could help to identify the cause of the mismatch.

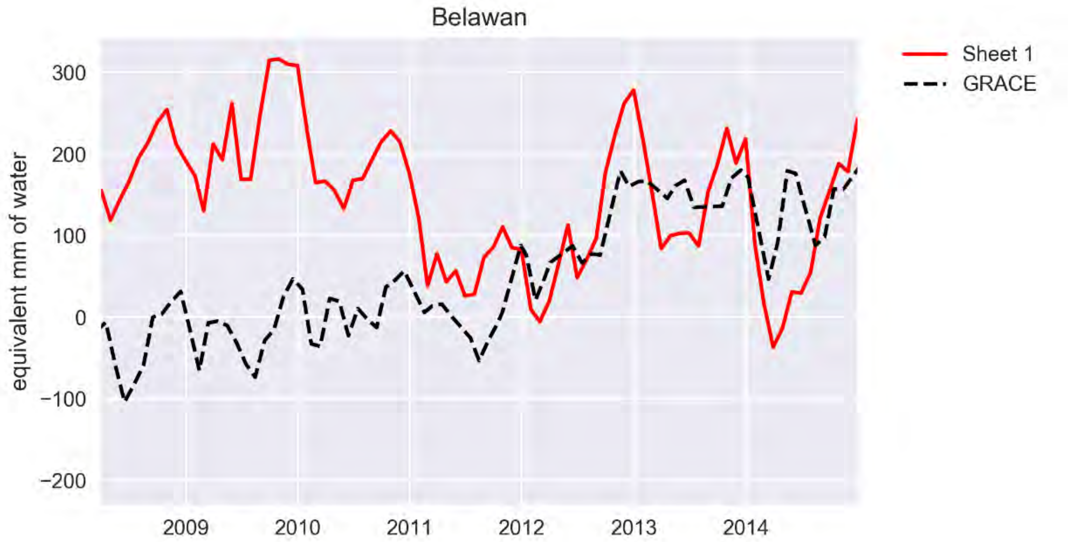

Figure 25: Total water storage relative to arbitrary reference, Belawan

7.3.2 Water Consumption (ET) & Agricultural Production

120. Water consumption through evapotranspiration remains stable over the dry, average and wet years analyzed with values between 1323 and 1362 mm/y representing between 44 and 59% of the precipitation in the respective years.

121. As in the other basins, a reduction of the proportion of transpiration relative to evaporation and interception during the wettest year analyzed (2009) due to more humid conditions leads to a reduction in the percentage of beneficial ET: from 50% for the driest year, to 44% for the wettest (see Table 16).

Table 16: Summary of evaporative consumption for Belawan

	ET	E	T	I	Beneficial		Non Beneficial	
YEAR	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*% of ET*	*mm/yr*	*% of ET*
2014	1362	265	702	395	685	50	676	49
2012	1334	232	610	491	593	44	740	55
2009	1323	217	612	493	594	44	729	55

122. Due to persistent cloud cover over part of the year for the study area, the crop growing seasons could not be estimated using remote sensing and standard values from the FAO for the island of Sumatra were used. Irrigated rice was assumed to have two growing seasons: from August to March and April to July, and rainfed rice a single growing season from October to April.

123. Crop water consumption is the water consumed through ET over cropped areas during the growing season. The average values for irrigated and rainfed areas are summarized in (Table 17).

Table 17: Crop Water Consumption, Belawan

	Crop Water Consumption	
	Rainfed	**Irrigated**
YEAR	*mm/yr*	*mm/yr*
2014	110	101
2012	311	173
2009	306	171

124. A useful measure of cropped areas is the land productivity expressed in kg/ha/year. Rice is the major crop grown in Belawan, the land average land productivities were found to be between 1078 and 3815 kg/ha/year for rainfed rice and between 2260 and 4464 kg/ha/year for irrigated rice (Table 18).

125. It should be noted that this study was carried out using a single land use map and therefore any changes over time in cropped or irrigated areas are not reflected in the results presented here.

126. Water productivities for rainfed rice are between .47 kg/m^3 and .5 kg/m^3 for rainfed rice and at .41 kg/m^3. These values are below the global average of 1.1 kg/m^3 for paddy rice.

127. In contrast to the situation in other basins, water productivity for irrigated crops does not go up in Belawan, and is even slightly reduced. This could be due to erroneous classification of rainfed crops as irrigated crops: the consumed water will be counted over the two standard growing seasons but crop growth would only occur in one season leading to a decrease in computed water productivity.

Table 18: Land and Water Productivity, Belawan

		Land Productivity		Water Productivity	
		Rainfed	**Irrigated**	**Rainfed**	**Irrigated**
YEAR	**Crop Type**	*kg/ha/year*	*kg/ha/year*	*kg/m3*	*kg/m3*
2014	**Other crops**	2521	2521	0.19	0.19
	Rice	1078	2260	0.47	0.41
2012	**Other crops**	2451	2451	0.19	0.19
	Rice	3815	4464	0.5	0.41
2009	**Other crops**	2402	2402	0.19	0.19
	Rice	3620	4422	0.48	0.41

7.3.3 Water Supply

128. The total withdrawals in the basin were estimated using the WaterPix model. The model estimates additional supply based on the concept of green and blue ET: green ET is the evapotranspiration which can be explained by rainfall alone and can be computed using an empirical equation. If total measured ET is found to be higher than this value, we can assume that an additional source of water had to be added to generate the ET amounts measured, and from this calculate supply.

129. Withdrawals in the basin were found to vary dramatically between the wet and dry years analyzed (see Table 24). The withdrawals in Seputih were those which were the most reduced during the wet year of 2010.

130. The majority of the manmade withdrawals are used for irrigation purposes with these accounting for between 51 and 61% of gross withdrawals. Residential water supply and aquaculture are the next largest users, accounting for between 15 and 26% of the total manmade water supply for residential uses and between 9 and 15% for aquaculture. The residential water demand was estimated based on population density maps.

Table 19: Total withdrawals, Belawan

	Manmade					Natural		
	Gross Withdr.	**Consumed**			**Non Cons.**	**Gross Withdr.**	**Consumed**	**Non Cons.**
		ETb	**ETb/Supply**	**Other**			**ETb**	
YEAR	*mm/yr*	*mm/yr*	*%*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*
2014	1007	210	20	538	258	170	168	1
2012	480	69	14	252	159	71	69	1
2009	344	53	15	181	109	45	44	1

7.3.4 Surface Water & discharge

131. The amount of runoff generated was estimated using the WaterPix model. The spatial distribution of runoff generation is shown in Figure 25.

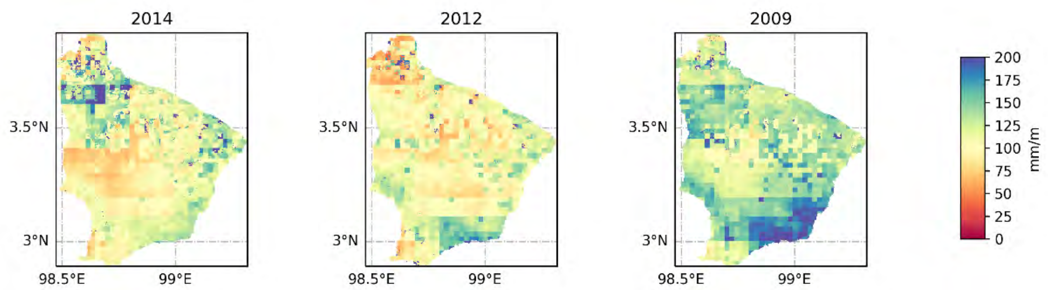

Figure 26: Average monthly runoff, Belawan

132. Discharge was estimated by routing the runoff using the SurfWat tool, which is a flow accumulation model developed at IHE Delft. The reservoir simulation module of the tool is still under development, and in the absence of reservoir release data, they were not included in the study.

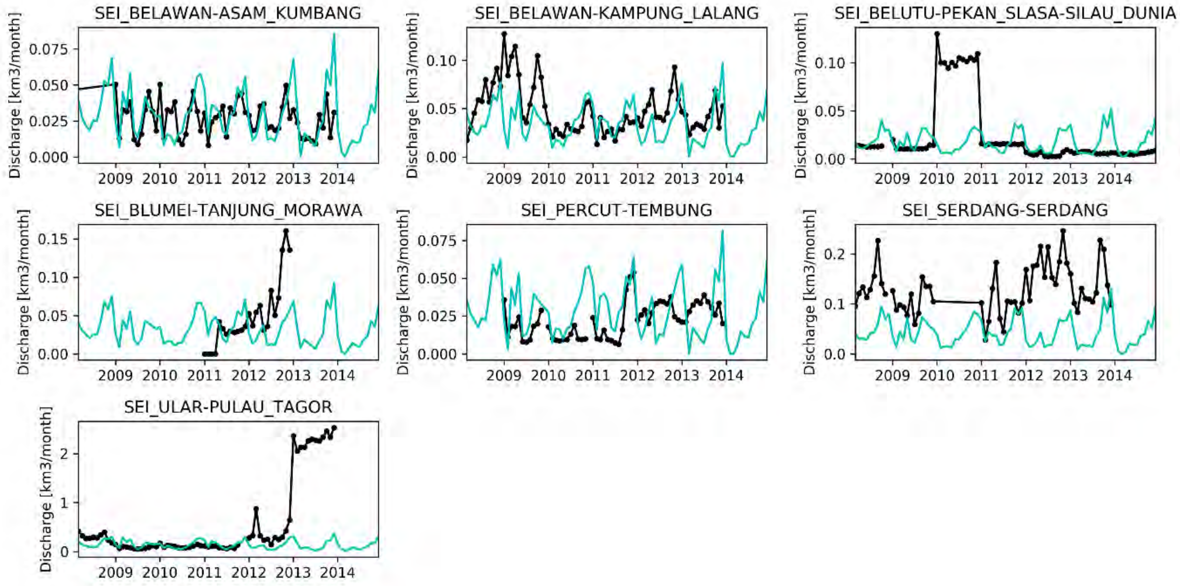

Figure 27: Estimated (cyan) and in-situ (black) discharge, Belawan

133. This can explain that while there is general agreement in order of magnitude and timing of discharge (Figure 19), the high flows simulated in SurfWat tend to be higer than those observed, and the dry season flows can be seen to sometimes drop to 0 where reservoir releases would in practice take up some of the water demand.

134. Belawan is the basin for which discharge remains highest even during the dry months. However, as with the other basins, utilizable outflow does fall to zero every year (Figure 27).

135. This indicates that any further water resource exploitation in the basin will need to rely on storages, surface or groundwater to avoid tapping into the committed flows. These committed flows are estimated environmental water requirements.

136. Considering the magnitude of utilizable outflows during the wet season, surface water storages could help spread out available water throughout the year.

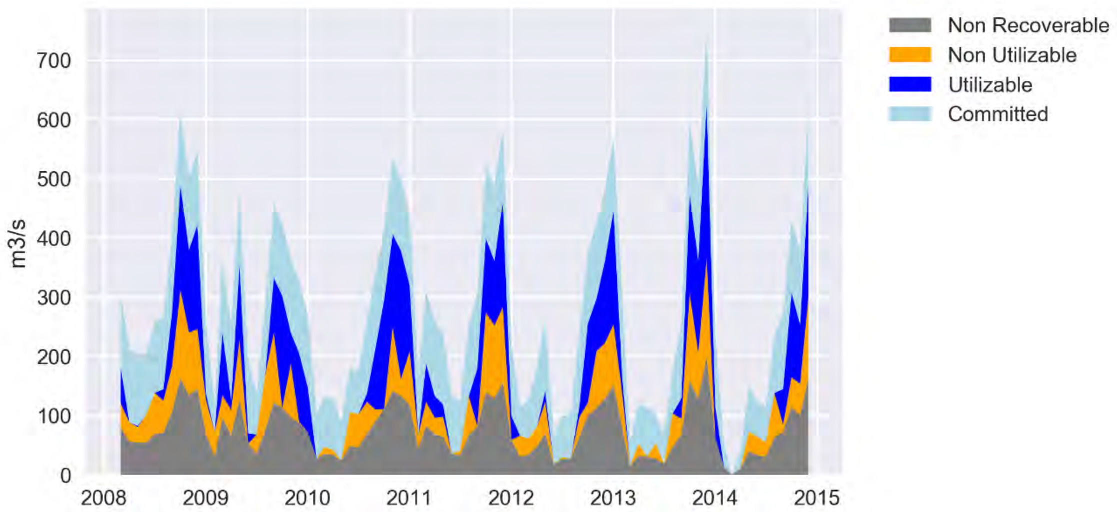

Figure 28: Utilizable and other outflows, Belawan

7.4 Seputih-Tulang Bawang River Basin

7.4.1 Basin scale water availability

137. On a yearly basis, the Seputih river basin was found to have sufficient water resources, with water yields remaining positive (see section 6.4, Figure 9). The relative magnitudes of the inflows and outflows of the basin are presented in Figure 28.

138. Water availability is however highly seasonal (Figure 18) with negative basin-averaged water yields for the months of August and September (see section 6.4, Figure 10).

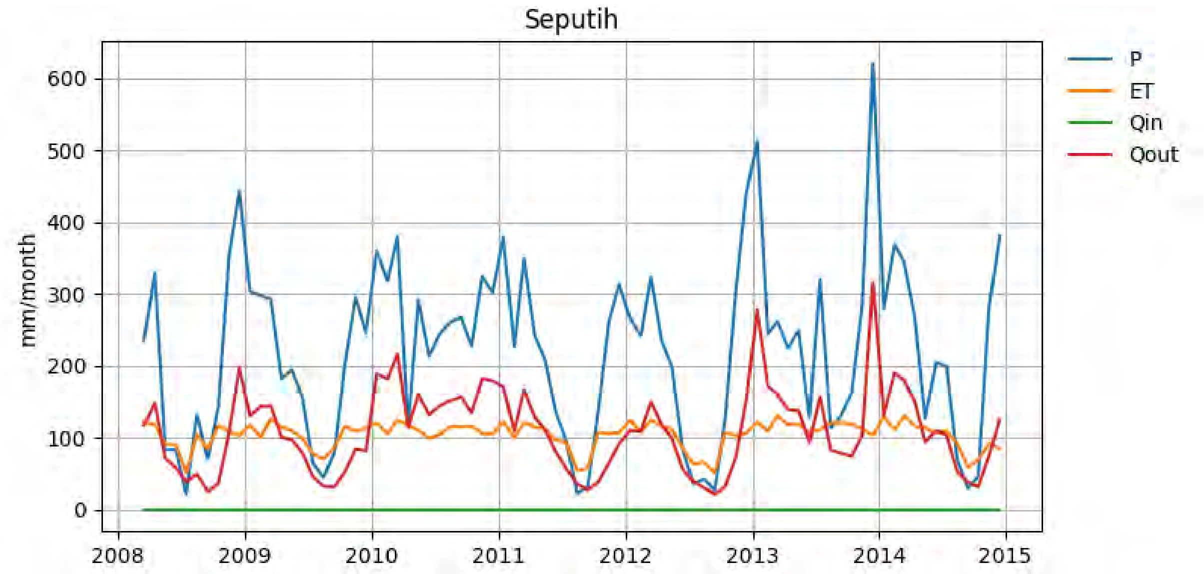

Figure 29: Inflows and Outflows, Seputih

139. For the average and low precipitation years, the analysis showed a small decrease in total storage (positive Delta S in Table 20) in the basin, while the wet year shows a small increase (negative Delta S in Table 20). These changes in storage represent only between .4 % and 0.7 % of the precipitation and are therefore well within the expected error of the input data and no major conclusions can be drawn based on the absolute values of the changes in storage. However their small values and the stable multiannual storage indicate a balance between the water inputs and outputs for the basin.

Table 20: Summary of in and outflows, Seputih

	Precipitation	ET	Delta S	Qin	Qout	Qin	Qout
YEAR	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*m3/s*	*m3/s*
2009	2353	1343	10	0	1020	0	477.23
2014	2589	1324	10	0	1275	0	596.85
2010	3300	1339	-23	0	1937	0	906.68

140. In practical terms this means the study did not reveal an issue of overexploitation of water resources in the basin under current conditions. This is also reflected in the long-term stability of total and groundwater storage in the basin (Figure 29).

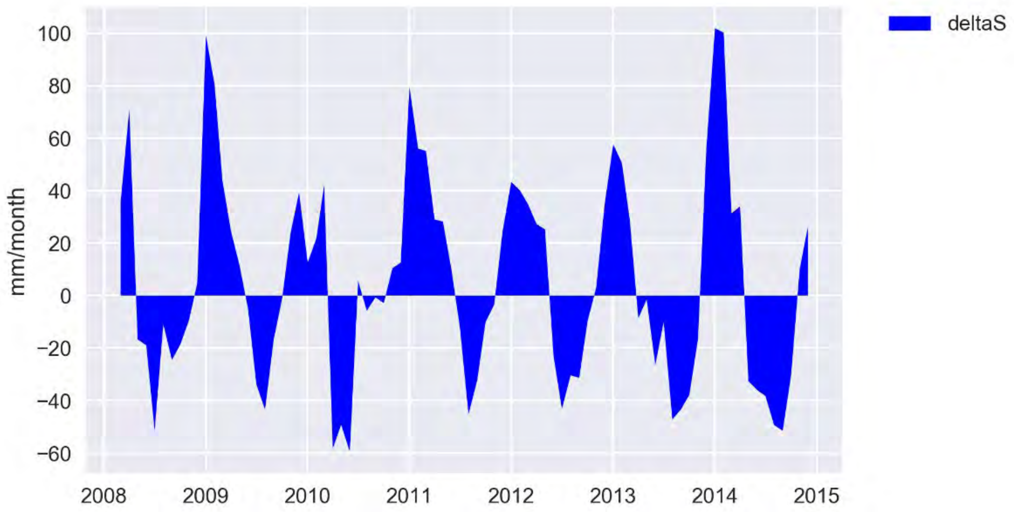

Figure 30: Groundwater storage variations, Seputih.

141. Total storage variations in the basin were found to be in agreement with those observed by the Gravity Recovery and Climate Experiment (GRACE, Figure 30).

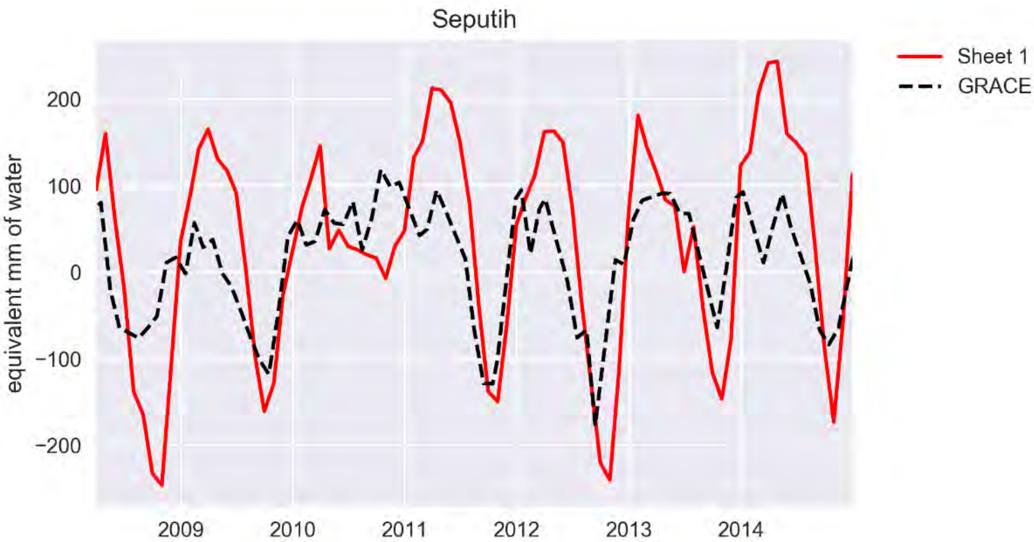

Figure 31: Total water storage relative to arbitrary reference, Seputih

7.4.2 Water Consumption (ET) & Agricultural Production

142. Relative to precipitation, evapotranspiration (ET) has a lower inter-annual variability. The amount of water consumed through ET varies between 41 % of precipitation for the wettest year and 57 % of precipitation for the driest year analyzed.

143. While ET was found to be highest for the wet year analyzed, and the portion of ET going to transpiration (T) and therefore directly linked to plant growth decreases for the wettest year (2010, see Table 21). This is typical in humid conditions.

144. The drop in transpiration and relative increase of evaporation (E) and interception (I) explains the drop in percentage of beneficial ET from above 65% for the average and dry years to 56% for the wet year (Table 21Table 4). This is because all transpiration is considered a beneficial water consumption as it represents a use directly contributing to pant growth and therefore the agricultural and economic sectors. Many other evaporative consumptions (for example soil evaporation) are considered non-beneficial.

Table 21: Summary of evaporative consumption, Seputih

	ET	**E**	**T**	**I**	**Beneficial**		**Non Beneficial**	
YEAR	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*% of ET*	*mm/yr*	*% of ET*
2009	1342	204	920	217	927	69	414	30
2014	1323	228	883	211	895	67	427	32
2010	1338	276	740	321	757	56	581	43

145. Due to persistent cloud cover over part of the year for the study area, the crop growing seasons could not be estimated using remote sensing and standard values from the FAO for the island of Sumatra were used. Irrigated rice was assumed to have two growing seasons: from August to March and April to July, and rainfed rice a single growing season from October to April.

146. Crop water consumption is the water consumed through ET over cropped areas during the growing season. The average values for irrigated and rainfed areas are summarized in (Table 22).

Table 22: Crop water consumption, Seputih

	Crop Water Consumption	
	Rainfed	**Irrigated**
YEAR	*mm/yr*	*mm/yr*
2009	353	372
2014	172	241
2010	351	373

147. A useful measure of cropped areas is the land productivity expressed in kg/ha/year. Rice is the major crop grown in Seputih, the average land productivities were found to be between 914 and 3261 kg/ha/year for rainfed rice and between 3217 and 6323 kg/ha/year for irrigated (Table 23).

148. It should be noted that this study was carried out using a single land use map and therefore any changes over time in cropped or irrigated areas are not reflected in the results presented here.

149. Water productivity also goes up for irrigated crops, with values between .53 kg/m3 and .64 kg/m3 for irrigated rice vs. values between .39 kg/m3 and .44 kg/m3 for rainfed rice (Table 23). These values are below the global average of 1.1 kg/m^3 for paddy rice.

150. The lower water productivity observed in the wettest year is a consequence of the same process leading to a lower proportion of transpiration in humid conditions.

Table 23: Land and Water Productivity, Seputih

Land Productivity		**Water Productivity**	
Rainfed	**Irrigated**	**Rainfed**	**Irrigated**

YEAR	Crop Type	*kg/ha/year*	*kg/ha/year*	*kg/m3*	*kg/m3*
2009	**Rice**	3261	6323	0.44	0.64
	Feed crops	6745		0.8	
	Other crops	3346	3346	0.25	0.25
2014	**Rice**	914	3217	0.41	0.61
	Feed crops	1838		0.76	
	Other crops	3187	3187	0.24	0.24
2010	**Rice**	2928	5500	0.39	0.53
	Feed crops	5734		0.69	
	Other crops	2749	2749	0.2	0.2

7.4.3 Water Supply

151. The total withdrawals in the basin were estimated using the WaterPix model. The model estimates additional supply based on the concept of green and blue ET: green ET is the evapotranspiration which can be explained by rainfall alone and can be computed using an empirical equation. If total measured ET is found to be higher than this value, we can assume that an additional source of water had to be added to generate the ET amounts measured, and from this calculate supply.

152. Withdrawals were found to vary dramatically between the wet and dry years analyzed (see Table 24). The withdrawals in Seputih were those which were the most reduced during the wet year of 2010. Seputih was found to have much lower withdrawals than the other 3 pilot basins.

153. The majority of the manmade withdrawals are used for irrigation purposes with these accounting for between 61 and 64% of gross withdrawals. Residential water supply is the second largest user, accounting for 16 to 22% of the total manmade water supply. The residential water demand was estimated based on population density maps.

Table 24: Total withdrawals, Seputih

	Manmade					Natural		
	Gross Withdr.	Consumed			Non Cons.	Gross Withdr.	Consumed	Non Cons.
		ETb	ETb/Supply	Other			ETb	
YEAR	*mm/yr*	*mm/yr*	*%*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*
2009	190	75	39	48	67	150	148	1
2014	249	92	37	66	90	158	151	7
2010	4	1	21	1	2	9	9	0

7.4.4 Surface Water & Discharge

The amount of runoff generated was estimated using the WaterPix model. The spatial distribution of runoff generation is shown in Figure 30.

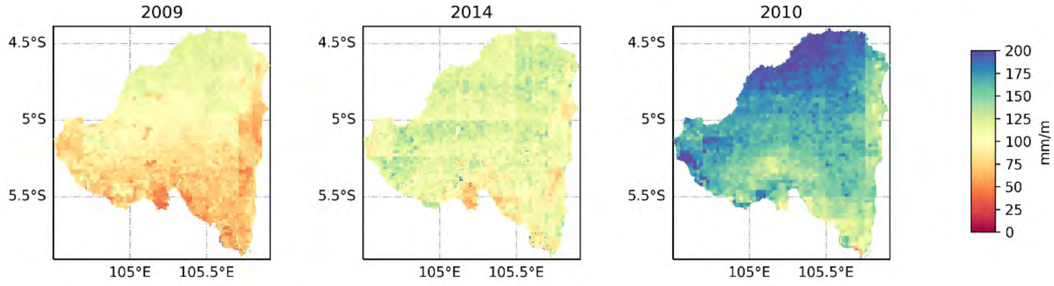

Figure 32: Average monthly runoff, Seputih

154. Discharge was estimated by routing the runoff using the SurfWat tool, which is a flow accumulation model developed at IHE Delft. The reservoir simulation module of the tool is still under development, and in the absence of reservoir release data, they were not included in the study. This can explain that while there is general agreement in order of magnitude and timing of discharge (Figure 31), the high flows simulated in SurfWat tend to be higer than those observed, and the dry season flows can be seen to sometimes drop to 0 where reservoir releases would in practice take up some of the water demand.

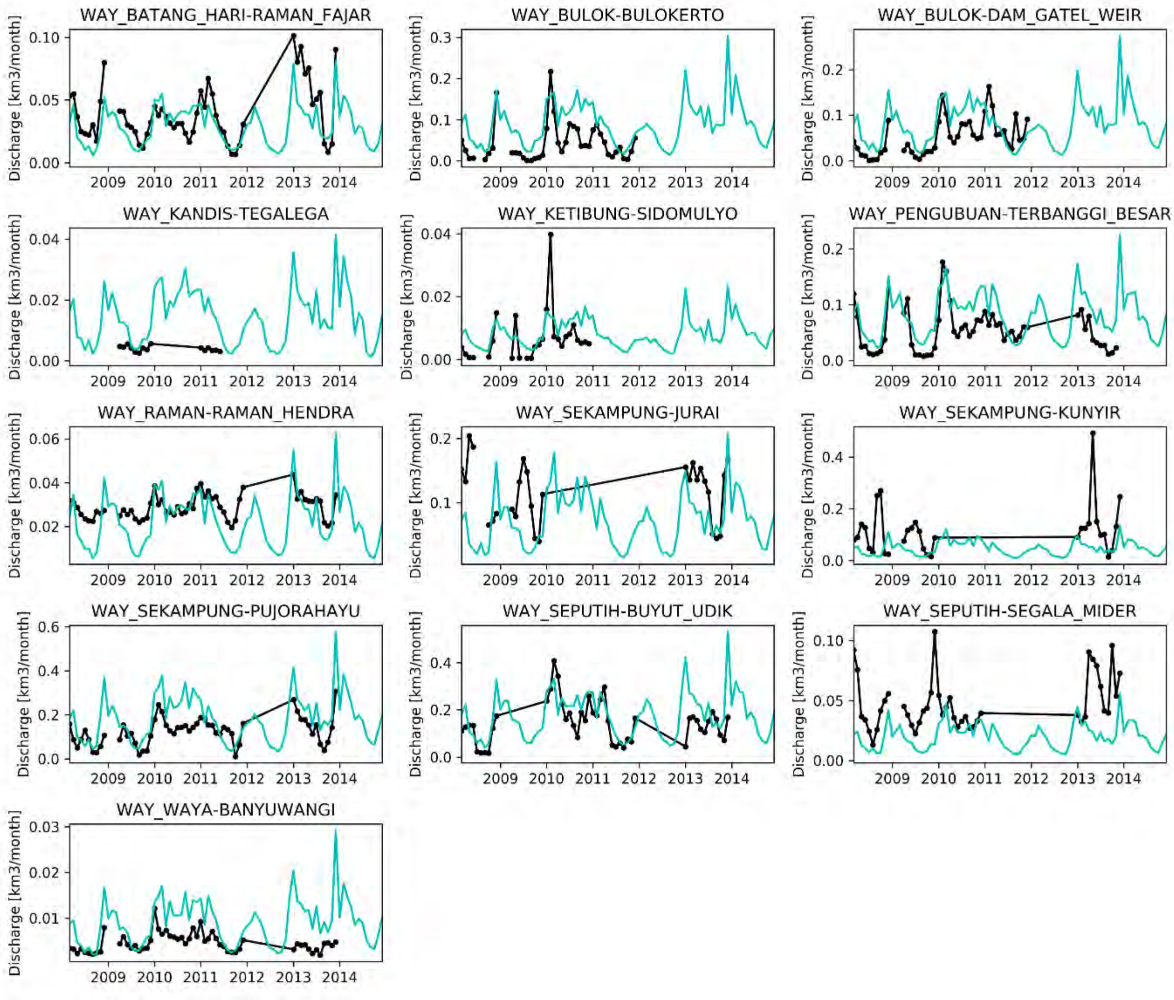

Figure 33: Estimated (cyan) and in-situ (black) discharge, Seputih

155. Even without representation of surface water impoundments, the basin-wide runoff generated minus the surface water abstractions does not fall to zero in the dry season. However, the utilizable portion of the outflow does (see Figure 32).

156. This indicates that any further water resource exploitation in the basin will need to rely on storages, surface or groundwater to avoid tapping into the committed flows. These committed flows are estimated environmental water requirements.

157. Considering the magnitude of utilizable outflows during the wet season, surface water storages could help spread out available water throughout the year.

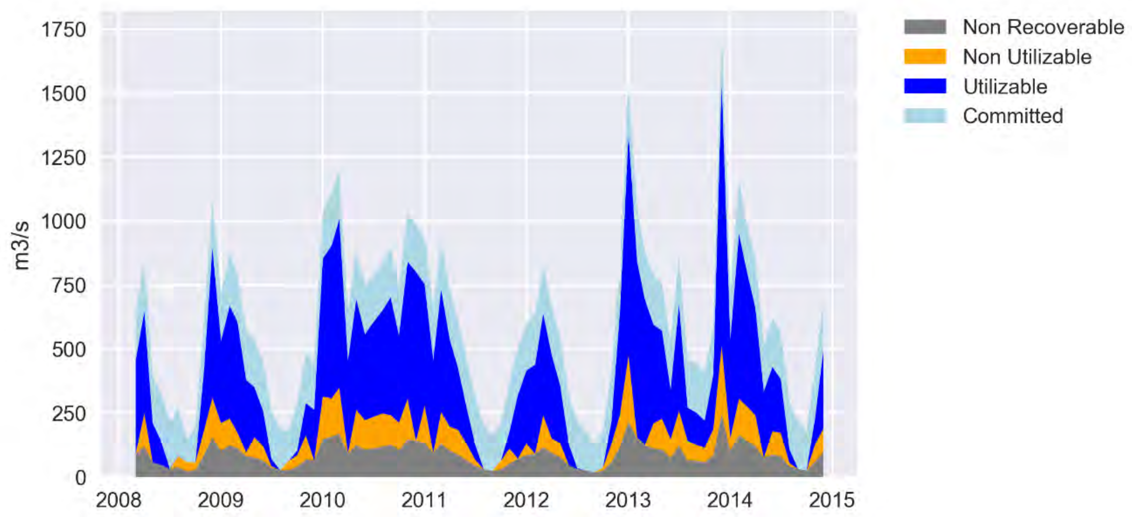

Figure 34: Utilizable and other outflows, Seputih

8 Summary conclusions for all basins

8.1 Current conditions

- On a basin and yearly scale, all four pilot basins were found to have sufficient water resources under current conditions.
    - No long-term depletion of storages observed
    - Current abstractions are sustainable on the basin scale
- Seasonal water availability is very variable for all basins with particularly high variability for the Cimanuk, Jratunseluna and Seputih basins. This has the following consequences:
    - Reliance on storages in the dry season
    - No utilizable flow left-over in dry season
    - High utilizable outflow during the wet season except for the Jratunseluna basin
- High inter-annual variability in water availability
- Non recoverable outflows are high for the two basins located on Java Island
- Jratunseluna is the basin for which the water situation is the most difficult due to a long period of negative water yields coupled with a high rate of water pollution.
- Water productivities were found to be low for all basins.
- Field application efficiencies are low

8.2 Perspectives & recommendations

- Scenarios from climate models predict that precipitation will increase in wet months and decrease in dry months over Indonesia, thereby further increasing the current seasonal water availability disparities (see for example http://sdwebx.worldbank.org/climateportal/).
- High utilizable outflows in the wet season can be stored for use in the dry season through carefully planned surface water storages
- Water storages may also be needed to mitigate annual-scale rainfall variations, especially for basins on Java Island.
- With further data, in particular the representation of current surface water storages, the analysis could be help better estimate any future shortages in bulk water supply to improve planning of future storages
- Analysis of flooding patterns in the basins would allow for a more accurate representation of the proportion of utilizable/non-utilizable outflows left over during the wet season for planning of surface water storages
- The coastal location of the basins, coupled with sea level rise means that any reliance on groundwater supplies runs the risk of salt water intrusion to the aquifers and should be very carefully considered.

- Low water productivities indicate potential for increased production without additional water supply
  - In a water productivity study, Cai et al. (Water Productivity Assessment for Improved Irrigation Performance and Water Security in the Asia-Pacific Region: Indonesia, 2018) found that in their study areas in Indonesia examples of high and low water productivity areas could be found and recommended analyzing high performing areas to help inform potential improvements in low-performing areas.
- Field application efficiencies are low, and non-beneficial ET was found to be between 30 and 55% of total ET
  - Irrigations amounts could be reduced further during times of high rainfall
  - On-farm water conservation techniques should be used (see also Cai et al., 2018)

8.3 Study limitations:

- Current surface impoundments were not modeled in this study
- A single land use map was used for each basin, any land use changes (including extension of irrigated areas) over time are therefore not represented.
- The model was run for the years 2008-2014, however 2015 was a very dry year and should be analyzed in the future.