Available online at:
http://journal.unila.ac.id/index.php/tropicalsoil
DOI: 10.5400/jts.2013.18.2.169

Impact of Land Use Change and Land Management on Irrigation Water Supply in Northern Java Coast

Suria DarmaTarigan and Rudolf Kristian Tukayo

Department of Soil Sciences and Land Resources, Bogor Agriculture University, Bogor 16680, Indonesia. Telp/Fax: +62-251-8629360/+62-251-8629358, e-mail: surya.tarigan@yahoo.com

Received 19 November 2012 / accepted 2 May 2013

ABSTRACT

In Indonesia, paddy irrigation covers an area of 7,230,183 ha. Ten percent (10%) of those area or 797,971 ha were supplied by reservoirs. As many as 237,790 ha (30%) of those area supplied by reservoirs are located in downstream of Citarum Watershed called Northern Java Coast Irrigation Area or Pantura. Therefore, Citarum watershed is one of the most important watershed in Indonesia. Citarum is also categorized as one of most degraded watershed in Java. The study aimed to evaluate the influence of land use change on irrigation water supply in Citarum watershed and to find the land management strategies to reduce the impact. Tremendous land use change occurred in the past ten years in Citarum watershed. Settlement areas increased more than a double during 2000 to 2009 (81,686 ha to 176,442 ha) and forest area decreased from 71,750 ha to 9,899 ha in the same time period. Land use change influences irrigation water supply through 2 factors: a) decreasing storage capacity of watershed (hydrologic functions) for dry season, and b) decreasing storage capacity of reservoirs due to the sedimentation. Change of Citarum watershed hydrologic function was analyzed using 24 years' time series discharge data (1984-2008) in combination with rainfall data from 2000 to 2008. Due to the land use change in this time period, discharge tend to decrease despite of increasing trend of rainfall. As a result irrigation area decreased 9,355 ha during wet season and 10,170 ha during dry season in the last ten years. Another threat for sustainability of water irrigation supply is reservoir sedimentation. Sedimentation rate in the past 10 years had reduced upper Citarum reservoir (Saguling) half-life period (½ capacity sedimented) from 294 to 28 years. If proper land management strategies will be carried out, the half-life period of Saguling reservoir can be extended up to 86,4 years

Keywords: Citarum watershed, improved land management, irrigation water supply, land use change, sedimentation

INTRODUCTION

Citarum River plays very important role in West Java economic activities. The river stretches from mountainous area in Southern of Bandung Regency to Northern Java Island with 299 km length. It supplies water for three important reservoirs used to generate electricity power, *i.e.* Saguling reservoir (982 million m^3), Cirata reservoir (2,165 million m^3) and Djuanda reservoir (3,000 million m^3). In addition, Djuanda reservoir is important water irrigation source for more than 240,000 ha irrigated paddy field in Northern Java. This irrigation area contributes to 60% national rice productions (ICWRM 2012). Irrigated paddy field in Northern Java coast is very strategic to the nation in term of food security. Recently, Government of Indonesia issued *Undang-Undang Perlindungan Lahan Pertanian Pangan Berkelanjutan (UU no.41/2009)* to attempt to secure productive irrigated paddy field area in the country or *lahan pangan abadi* and to prevent it from land conversion. Unlike other type of agriculture system, irrigated paddy fields are bound to their water resources coming from upper watersheds. Therefore, when a certain area of irrigated paddy field to be included as *lahan pangan abadi*, the upper watershed should be protected as well to secure future water supply necessary to feed those areas. In this respect, this study attempt to identify relationship between land use change and good land management in Upper Watershed Citarum the driver for water supply sustainability in Northern Java Coast Irrigation Area or Pantura.

Water supply in wet season is normally sufficient in years with normal rainfall. But, in dry season water deficit normally occurs. In the watershed where reservoirs are present like in Northern Java irrigated are, intensity of water deficit can be alleviated into a certain degree by reservoir buffering capacity. Nevertheless, rapid forest conversion in upper Citarum and improper conservation measures in agriculture areas worsen water deficit and threaten sustainability of its role in supplying water either for irrigation as well as for power generation. Role of forest in upper watershed is very important to increase infiltration. According to Bruijnzeel (2004), about 80–95% of incident rainfall infiltrates the soil in a mature tropical rainforest. Infiltrated water has a great impact on dry season stream flow. The higher the infiltrated water, the higher dry season stream flow (base flow) will be. The base flow is thus critical in determining the healthiness of streams where continuous flowing of water in the river is required to maintain the water supply (Yang *et al*. 2011). Zheng *et al*. (2009) reported that land use change played a more important role than climate in reducing stream flow over the last decades in the Yellow River Basin, China. Wang *et al*. (2012) indicated that even relatively minor land use changes had a significant effect on regional soil erosion rates and sediment transport to rivers.

It has been identified that 4 million cubic meter sediment entered Saguling reservoir per year (BP DAS Citarum Ciliwung 2008). Legowo *et al.* (2009) stated that sedimentation is such a crucial issue to be noted once the accumulated sediment begins to fill the reservoir dead storage, this will then influence the long-term reservoir operation. According to Shi *et al*. (2012) soil erosion poses a serious problem for sustainable agriculture and the environment. Owing to long-term anthropic pressure including overuse and inappropriate development, soil erosion has become a serious issue in the Three Gorges Area (TGA), China. It reduced life storage capacity of the reservoir sharply. High sedimentation was presumed due to the land use change especially increased dry land farming activity in Upper Citarum catchment. According to *Yan et al*. (2013) the dominant first-order factors affecting the changes in sediment yield in their study were proportion of farmland and forest in the catchment. Kimwaga *et al.* (2012) indicated that expansion of agriculture in the Simiyu catchment of Lake Victoria increased sediment loading to the lake.

Objective of the research was to analyze impact of land use change and improper land management in Citarum catchment on the irrigation supply to Northern Java irrigation area and possible land management strategy to reduce the impact.

MATERIALS AND METHODS

Time and Location

The research was carried but in Citarum Watershed in 2010-2011. Citarum watershed is situated in West Java Province. The study was started from Upper Citarum watershed and then finally covered the whole Citarum watershed. There

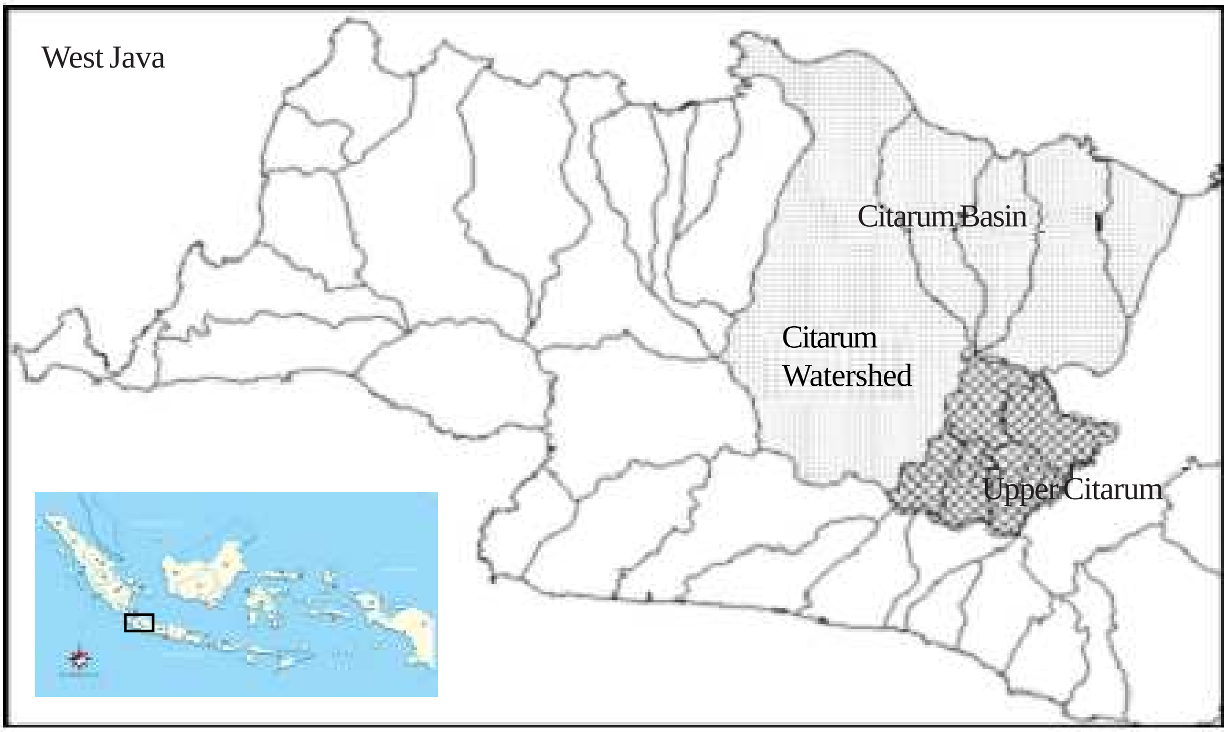

Figure 1. Research location including Upper Citarum, Citarum Watershed and Citarum Basin. Note: Citarum Basin including Citarum Watershed and several interrelated watersheds in Downstream (BBWSC 2011).

are three reservoirs in the Citarum watershed. Two reservoirs were directly taken into consideration in this study *i.e*. Saguling reservoir and Djuanda Reservoir. Saguling reservoir is situated in Upper Citarum Watershed and Djuanda reservoir is situated downstream of Citarum Watershed.

Type of Data Collection Including Following Parameters:

Data were collected from (1) amount of catchment water yield at reservoir inlet, irrigation requirement, irrigation supply, irrigated area from 2002 until 2009 were obtained from *Perum Jasa Tirta II Jatiluhur* and (2) yearly rainfall data from 2002 until 2009 were obtained from *Perum Jasa Tirta II Jatiluhur.*

Data Analysis

Erosion prediction for Upper Citarum Watershed was calculated using USLE equation and GIS procedures. For erosion calculation, C (crop factor) value was derived from land use year 2009 issued by KLH (Ministry for Environment), LS (slope factor) were determined from SRTM 30 m, K (soil factor) from Soil Research Institute Bogor and R (rain erosivity) was based on Bols (1978).

Yearly average discharge both to Saguling and Djuanda Reservoir inlets were plotted using linier trend line.

Reservoir efficiency was calculated based on the following equation (Perum Jasa Tirta II 2001): Reservoir efficiency (%) = ((yearly water deficit in watershed scale – water deficit in reservoir)/ water deficit in reservoir) × 100%.

Impact of land management on reservoir life time was calculated based on the following equation (Verhaeghe *et al*. 2010): Remaining half life time (in years) = reservoir half-life storage in year/ (erosion in t $ha^{-1}yr^{-1}$*sediment delivery ratio* sediment specific weight in t m^{-3}* trapping rate in the reservoir in %/ sediment bulk density in the reservoir).

RESULTS and DISCUSSION

Impact of Land Use Change on Water Resources in Citarum Watershed

Based on BBWSC (2011), settlement areas increased from 81,686 ha to 176,442 ha, which was more than a double during 2000 to 2009 in Citarum river basin. In the same time frame, forest area decreased from 71,750 ha to 9,899 ha (Figure 2).

Impact of land use change and poor land management on water resources can be categorized into two aspects: (1) decrease of forest area and increase of built up area will increase runoff coefficient which in turn will decrease low flow during dry season and (2) poor land management in dry land farming will increase erosion which in turn will cause sedimentation of reservoir.

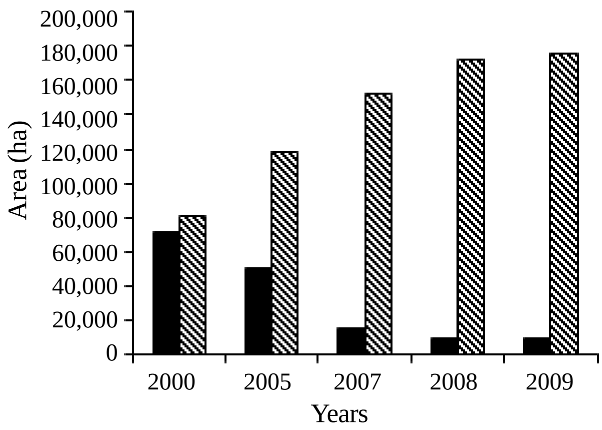

Figure 2. Land use change during 2000-2009 in Citarum Watershed. ■ = forest and ▨ settlement.

Water Yield

Dry season discharge of Upper Citarum Watershed or Saguling catchment show significant decrease in the last 10 years (Figure 3).

Since proportion of upper Saguling catchment area was more than half of Citarum catchment (58.6%), decrease in its water yield would in turn affect discharge to Cirata and Jatiluhur reservoirs situated downstream to Saguling reservoir.

Saguling Reservoir Sedimentation

Land use change in upper Citarum had accelerated erosion and in turn increased amount of sediment entering Saguling reservoir. Reservoir sedimentation will decrease the amount water stored during dry season. Besides, reservoir sedimentation will reduce its lifetime. More than 4 million tons sediment settled in the reservoir every year.

Low Flow Discharge

Citarum River is the main source for water irrigation in Pantura area. Despite the decreasing trend in water yield, river discharge is enough to supply irrigation demand during wet season. But, during dry season, low river discharge becomes limiting factor in irrigation supply. Time series data for dry season (July – September) showed a drastic change of low flow discharge in the period of 1984 — 2008 (Figure 4). The decreasing trend was not

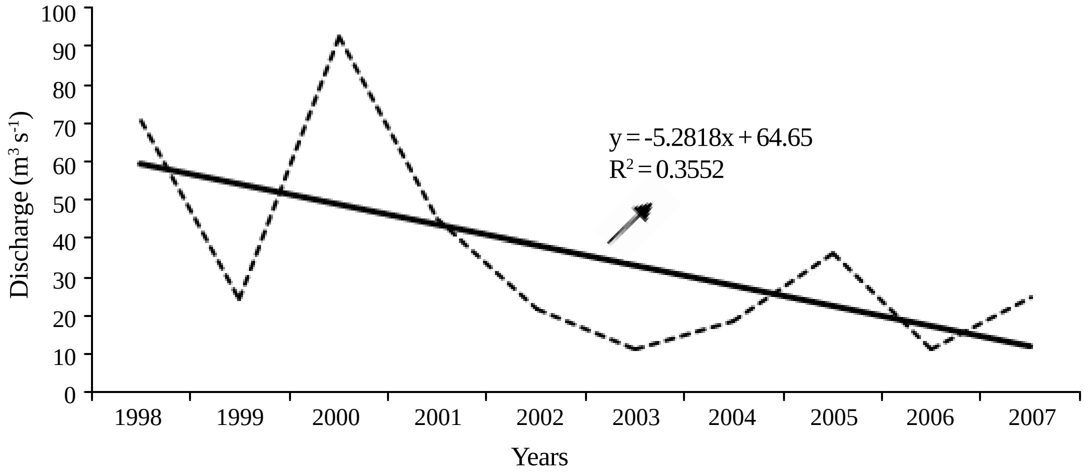

Figure 3. Yearly average discharge to saguling reservoir inlet (dashed line) and trend line (solid line).

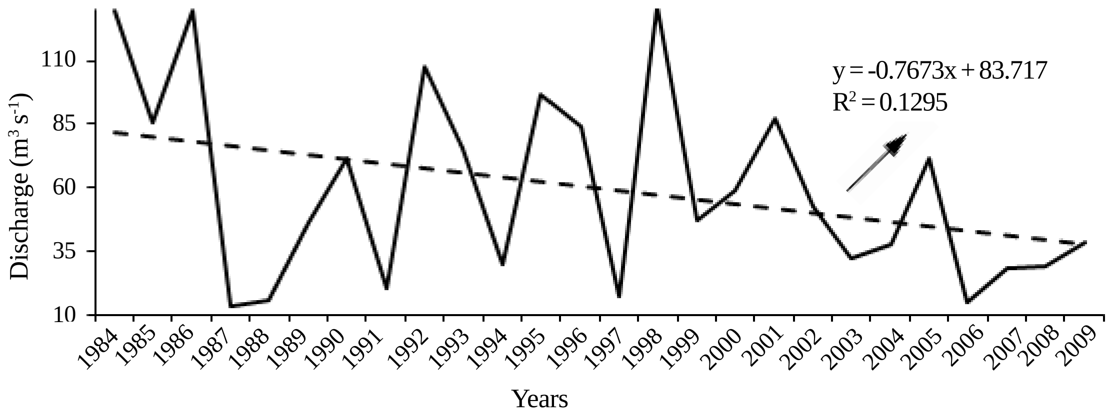

Figure 4. Decreasing average of Citarum discharge in dry season (solid line) with trend line (dashed line).

due to the change of rainfall, because in the same period amount of rainfall showed increasing trend.

Reservoir efficiency was likely to decrease from 2002 to 2008 due to the combination effect of decreasing inlet discharge and reservoir sedimentation (Figure 5). The smaller the efficiency, the bigger the reservoir deficit.

Impact of Land Use Change on Paddy Rice Planting Area

Rice field area in Citarum decreased continuously both in wet and also in dry season. In the period of 2002 to 2009 or in 7 years, irrigated area in Pantura decreased about 9,355 ha in wet season and about 10,170 ha in dry season (Figure 6). The decrease was occurred 93.77% in Tarum Barat and 6.33% in Tarum Timur. In Tarum Utara irrigated area remained constant. The decrease of irrigated area could be attributed either to land conversion or water deficit in dry season.

The decrease of irrigated area in wet season was most probably due to the land conversion. In

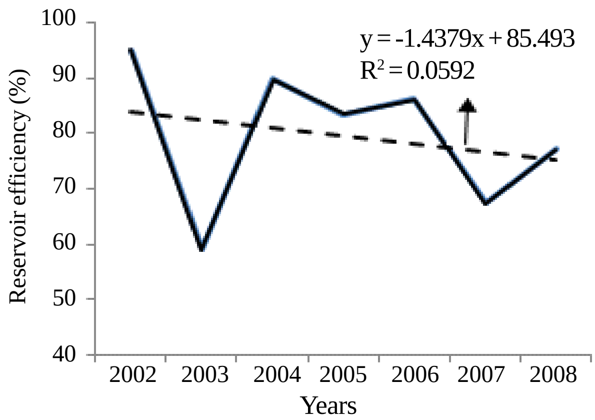

Figure 5. Decreasing efficiency of Djuanda Reservoir.

wet season (November until April) there was always water surplus. It means, the decreasing in irrigated area was not caused by water deficit. Decrease of irrigated area during rainy season in the last 7 years must be due to the land conversion. In contrast with rainy season, in dry season water is the limiting factor for irrigated area. Decreasing rate of irrigated

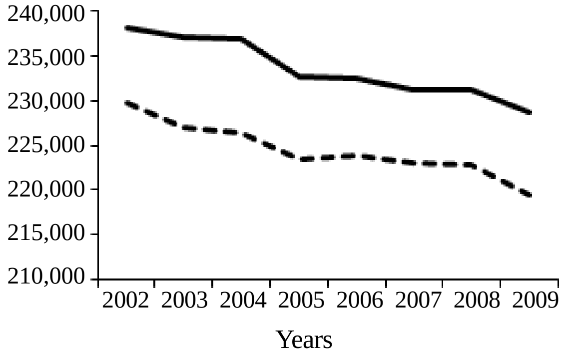

Figure 6. Total irrigated paddy field area in Northern Java Coast in rainy and dry season (Tukayo 2011). ▬▬ = dry season and ▬ ▬ ▬ = rainy season.

area in dry season more than those in wet season was primarily due to the decreasing catchment water yield or river discharge in reservoir inlet (Figure 8). From mid of November to the end of April river discharge (catchment water yield) steadily exceeded irrigation requirement, but from beginning of May until mid of November water yield dropped below irrigation requirement and water deficit occurred in this time period. From May until July which was the beginning of third planting season, water supply from reservoir could not fulfill the entire water requirement (Figure 7).

Improved Land Management

To reduce sedimentation in reservoir, improved land management in dry land farming should be introduced. Based on erosion analysis in Upper Citarum Watershed, majority of sediment came from dry land farming (Figure 8). Improved land management in dry land farming is therefore of prime important. To simulate impact of improved land management on reservoir sedimentation, erosion prediction using USLE equation was carried out in Upper Citarum watershed. Result of erosion prediction on existing condition and improved good land management is shown in Table 1. The existing condition of dry land farming in Upper Citarum Watershed is sohwn in Figure 9. Improved management level represented moderate to high surface mulching application, maintenance of good ground cover by application of inter-cropping and crop diversification and application of good bench terraces (Verhaeghe *et al*. 2010). In addition, non-dry land farming having slopes steeper than 40% that are presently having bad ground cover were assumed to be reforested or planted with agroforestry system in erosion prediction. Existing management level in Table 1 represents the actual situation, in which some measurements like simple condition of mechanical management practices such as bund and bench terraces were applied.

Impact of Improved Land Management to Saguling Reservoir Sedimentation

Saguling reservoir was built in 1980-1986. In 2008 or 26 years after its construction the storage decreased about 180 MCM from 889 to 709 MCM or equals to 4 MCM per year.

Based on reservoir sediment survey carried out by Indopower in 2007 (BP DAS Citarum Ciliwung 2008), amount of sedimentation in Saguling reservoir during 1987 until 2007 was 84,644,878 m^3 or 4 Million t yr^{-1}. Based on this survey, SDR for the catchment was 4%. Due to the land use change

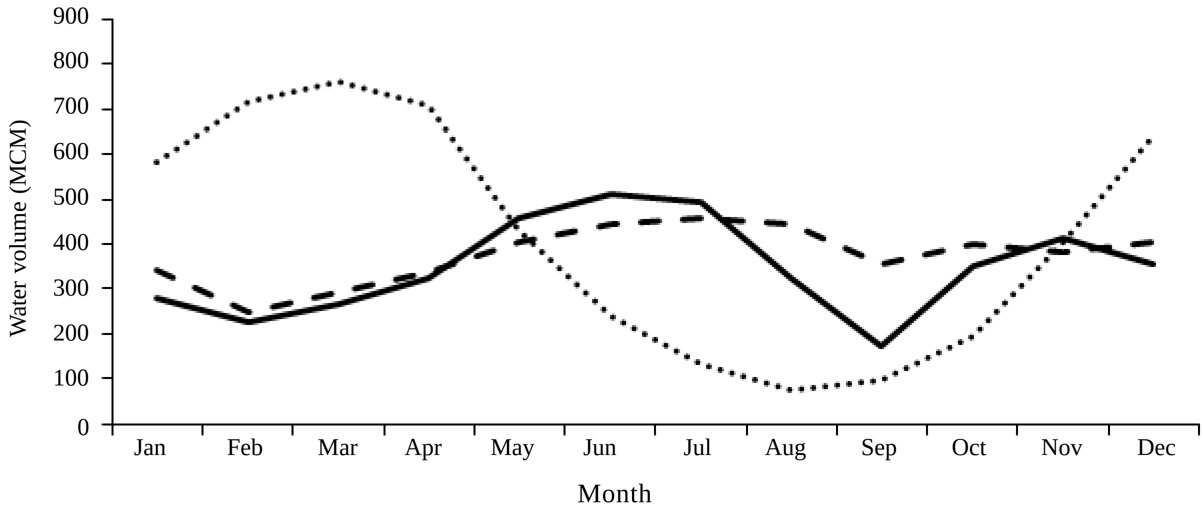

Figure 7. Monthly volume of catchment water yield in Djuanda Reservoir inlet, irrigation requirement and water supply by reservoir in MCM (million cubic meters) (Tukayo 2011). ▬▬ = irrigation requirement, •••••• = catchment water yield, and ▬ ▬ = reservoir supply.

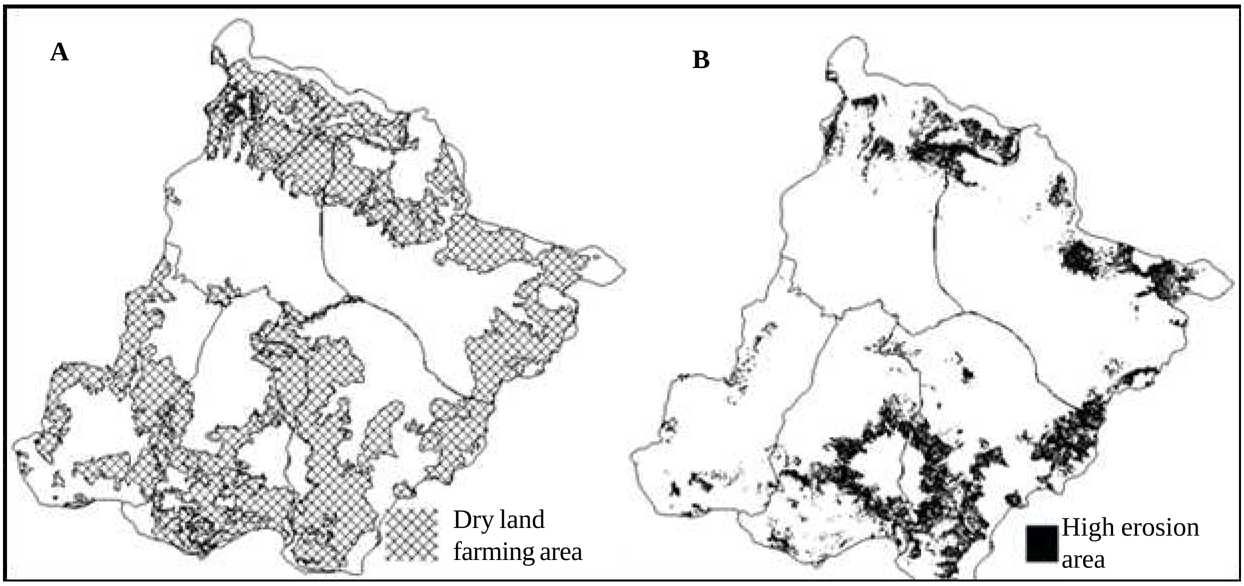

Figure 8. Location of dry land farming areas (A) are associated with location of high erosion area (B) in Upper Citarum Watershed.

Figure 9. Existing condition of dry land farming in Upper Citarum Watershed (Cita 2012).

and intensive development of build up area in Upper Citarum SDR of 4% was far too low. Therefore, the value of SDR taken was 20%. It means 80% of erosion figures will be retained in depression storage throughout the watershed and only 20% of the total erosion will enter the reservoir. According to erosion prediction in Table 1 and SDR value of 20%, the remaining time to fill the half-life storage for Saguling can be estimated as follows:

Based on (Verhaeghe *et al*. 2010) remaining half life time (in years) = reservoir half-life storage in year/(erosion in t ha^{-1} yr^{-1}*sediment delivery ratio* sediment specific weight in t m^{-3} * trapping rate in the reservoir in %/ sediment bulk density in the reservoir).

Remaining half life time (in years)= (889 MCM/2 – 180 MCM)/ (50,8*0.2*1.1*0.95/1.2) = 30 years

If improved effort is not taken to reduce amount of erosion in Upper Citarum then 60 years ahead, the reservoir will just become a full with sediment. With implementation of improved management level of soil and water conservation measures, assuming a transition from the present to the required condition in 7 years:

Table 1. Erosion prediction in different management condition in Upper Citarum.

Management Level	Management Practices	Erosion (million t yr^{-1})
Existing	Minimal application of surface mulching (<0.5 t ha^{-1}) and fertilizers. Some crop rotation in adjusment for market demand r. Low density mixed garden and low intensity inter-cropping, Maintaining of 20-40% ground cover. Only traditional terraces were applied	50.8
Improved	Application of high rates of surface mulching (> 3 t ha^{-1} yr^{-1}) and sufficient fertilizers. Maintaining very high ground covers (> 80%), inter-cropping and a high crop diversity. Construction of bench terraces for slope 15%. All slopes steeper than 40%, used presently for non-irrigated agriculture and mixed gardens are assumed to be under forest.	18.7

Sedimentation in the first 7 years:
Sediment volume in reservoir:
(50.8 + 18.7)*0.5*0.2*1.1*0.95/1.2 = 6.0 MCM
Time re+quired to further filling the reservoir until half storage:
258.5/(18.7*0.2*1.1*0.95/1.2) = 79.4 years
Remaining half life time is then 79.4 + 7 = 86.4 years. Implementation of proper land management strategy in Upper Citarum watershed will greatly improve reservoir life storage and also its life time.

CONCLUSIONS

Tremendous land use change occurred in Citarum watershed. Rapid development of settlement area had increased runoff coefficient substantially. Increasing of runoff coefficient had reduced low flow during dry season. Low flow in Citarum reduced from 85 to 35 m^3 s^{-1} in the time period from 1984 to 2008.

In the period of 2002 to 2009 or in 7 years, irrigated area in Pantura decreased about 9,355 ha in wet season and about 10,170 ha in dry season. The decrease of irrigated area in wet season was most probably due to the land conversion. In dry season, water is the limiting factor for irrigated area. Decrease rate in irrigated area in dry season more than those in wet season was primarily due to the decreasing catchment water yield or river discharge in reservoir inlet

Beside low base flow, water yield decrease was partly caused by reservoir sedimentation. Saguling sedimentation amounted to 4 million cubic meters per year. It reduces life storage capacity of Saguling reservoir from 294 to 30 years. If improved land management strategies be carried out the half-life period of Saguling reservoir can be extended up to 86.4 years.

REFERENCES

Asdak. 2004. Hidrologi dan Pengelolaan Daerah Aliran Sungai. Gadjah Mada University Press. Yogyakarta (in Indonesian).

BBWSC [Balai Besar Wilayah Sungai Citarum]. 2011. Peta Informasi Citarum 2011. Direktorat Jenderal Sumber Daya Air Departemen Pekerjaan Umum (in Indonesian).

Bols PL. 1978. Iso Erodents Map of Java Madura. Technical Assistant Project ATA 105. Soil Research Institute, Bogor, Indonesia. 39 pp

BPDAS [Balai Pengelolaan Daerah Aliran Sungai] Citarum Ciliwung. 2008a. Pengelolaan DAS Terpadu – DAS Citarum (Buku I: Laporan utama). BPDAS Citarum Ciliwung, Ditjen RLPS Dephut. Bogor (in Indonesian).

BPDAS [Balai Pengelolaan Daerah Aliran Sungai] Citarum Ciliwung. 2008b. Pengelolaan DAS Terpadu – DAS Citarum (Buku II: Data dan Informasi). BPDAS Citarum-Ciliwung, Ditjen RLPS Dephut. Bogor (in Indonesian).

Bruijnzeel LA. 2004. Hydrological functions of tropical forests: Not seeing the soil for the trees? *Agric Ecosyst Environ* 104: 185-228.

Cita. 2012. Dua puluh dua (22) *Hotspost in the Citarum River Basin*. www.citarum.org. Accesed on 10 October 2012.

ICWRM [Integrated Citarum Water Resources Management]. 2012. Atlas Pengelolaan Sumberdaya Air Terpadu Wilayah Sungai Citarum. *Cooperation between* ADB and Bappenas (in Indonesian).

Kimwaga RJ, F Bukirwa, N Banadda, UG Walic, I Nhapi and DA Mashauri. 2012. Modelling the impact of land use changes on sediment loading into lake

Victoria using SWAT model: A Case of Simiyu Catchment Tanzania. *Open Environ Eng J* 5: 66-76.

Legowo S, KI Hadihardaja and Azmeri. 2009. Estimation of bank erosion due to reservoir operation in cascade (Case Study: Citarum Cascade Reservoir). *ITB J Eng Sci.* 41: 148-166.

Perum Jasa Tirta II. 2001. Pengalaman Mengelola Bendungan Besar Waduk Ir. H. Djuanda. Perum Jasa Tirta II. Jatiluhur (in Indonesian).

Shi ZH, L Ai, NF Fang and HD Zhu. 2012. Modeling the impacts of integrated small watershed management on soil erosion and sediment delivery: A case study in the Three Gorges Area, China. *J Hydrol* 438: 156-167.

Tukayo RK. 2011. Evaluasi perubahan penggunaan lahan DAS Citarum dan dampaknya terhadap suplai air irigasi. [Thesis]. Institut Pertanian Bogor (in Indonesian).

Verhaeghe RJ, B. Adriaanse and SD Tarigan. 2010. Assessment of erosion sensitivity and watershed conservation interventions for Upper Citarum basin. TA 7189-INO: Institutional Strengthening for Integrated Water Resources Management (IWRM). 6Ci's River Basin Territory, Component B2: Spatial planning.

Wang G, H Jiang, Z Hu, L Wang and W Yue. 2012. Evaluating the effect of land use changes on soil erosion and sediment yield using a grid-based distributed modelling approach. *Hydrol Processes* 23: 35790-3592.

Yan B., NF Fang, PC Zhang and ZH She. 2013. Impacts of land use change on watershed stream flow and sediment yield: An assessment using hydrologic modelling and partial least squares regression. *J Hydrol* 484: 26-37.

Yang H H, O Jaafar, A El-Shafie and S Mastura, 2011. Impact of land-use changes toward base-flow regime in Lui and Langkat Dengkil sub-basin. *Int J Phys* Sci 6: 4690-4976.

Zheng H, L Zhang, R Zhu, C Liu, Y Sato and Y Fukushima, 2009. Responses of streamflow to climate and land surface change in the headwaters of the Yellow River Basin. *Water Resour Res* 45 (W00A19). doi: 10.1029/2007WR006665.