Indonesian Journal of Agricultural Science 12(2), 2011: 70-83

AN ALTERNATIVE METHOD OF REMOTE SENSING AND GIS FOR ASSESSING AGRICULTURAL DROUGHT IN UPPER BRANTAS WATERSHED, INDONESIA

Rizatus Shofiyati[a*)], Kiyoshi Honda[b], and Hidayat Pawitan[c]

[a]*Indonesian Center for Agricultural Land Resources Research and Development*
Jalan Tentara Pelajar No. 12, Bogor 16114, Indonesia. Phone +62 251 8323012, 8327215, Fax +62 251 8311256
E-mail: bbsdlp@litbang.deptan.go.id
[b]*School of Engineering and Technology (SET), Asian Institute of Technology (AIT), Thailand*
[c]*Faculty of Mathematics and Natural Sciences, Bogor Agricultural University (IPB), Indonesia*
[*)]*Corresponding author: rshofiyati@litbang.deptan.go.id*

Submitted 12 May 2011; Accepted 24 August 2011

ABSTRACT

In Indonesia, drought disasters have been reoccurring more frequently in recent years. The 1997-1998 El Nino had caused the worst drought to Indonesia in the last 50 years and disrupted rice production. Remote sensing (RS) and geographic information system (GIS) provide good capability to achieve spatially distributed information over wide area coverage and multi-temporal data to give sufficient information to anticipate those situations. The study aimed to develop a method using GIS combined with satellite data for monitoring and assessing agricultural drought in Brantas Watershed, Indonesia. The drought factors were determined based on expert knowledge analysis. Risk assessment method was developed using weighting which is determined based on significant factors of drought, i.e. rainfall pattern, irrigation status, ground water capacity, soil drainage, and land cover. Satellite data were used to analyze the characteristics of temporal variations of normalized difference vegetation index (NDVI) against drought factors. Weighting scores were determined by analyzing NDVI character using changes in NDVI and normal line diagram of each factor. The accuracy of drought risk map was evaluated by comparing drought risk level and NDVI value. The results indicated that expert knowledge analysis of the drought factors showed significant influence on NDVI value. Drought risk and drought status showed a high positive correlation with R^2 = 0.85 for NOAA AVHRR, meaning that there is a significant correlation between the two (r = 0.92). The results of this study can be used to determine spatially location of drought-prone areas based on bio-physical factor causes. Therefore, it can be make recommendation for prevention of agricultural drought in the future.

[***Keywords***: Agricultural land, drought, remote sensing, geographical information systems, Brantas Watershed]

INTRODUCTION

In Indonesia, drought disasters have been occurring more frequently in recent years. It was not only experienced in 1997 caused by El Niño (Puterbaugh 1997), but also occurred in 1987 as reported by Puslittan (1989) and in 1972, 1977, 1982, 1987, 1991 and 1994 as noted by Pasandaran and Hermanto (1997). It has occurred more frequently from 2002 to 2008, every two years (Makmur 2009). The 1997-1998 El Niño was the strongest in this century, where parts of Indonesia suffered serious drought as reported by FAO (1998) and World Meteorological Organization *in* Gathara *et al*. (2006).

Antara News reported that due to the change in land use in Brantas Watershed, some water resources have been decreasing. Reduction of water sources in the region can cause drought in the future (Wibisono 2010). To overcome these problems, historical spatial data of drought affected areas can help policy makers to decide recommendations of drought impact mitigation in the area. In this regard, special attention to monitor the condition is encouraged to reduce the damage. Sufficient data and information to anticipate various situations caused by drought are critical, as it would affect agricultural development. Spatial and temporal information is needed for planning in overcoming the effects of drought.

Remote sensing can provide a variety of spatial information and other multi-information, i.e. multi-spectral, multi-sensor, multi-spatial, multi-time, multi-polarization, and multi-stage (stage). Remote sensing techniques can provide spatial information, cover wide area, including remote area, and multi-temporal data for analysis. In last decade, a large number of studies have been conducted that demonstrated the usefulness of information derived from remote sensing and geographic information system (GIS) for drought monitoring (Thiruvengadachari *et al*. 1991; Gomarasca *et al*. 1993; Verbila 1995; Liu and Kogan 1996; Saint 1996; Tripathy *et al*. 1996; Datt 1999).

Other research conducted by Prathumchai *et al*. (2001) using JERS-1 Optical sensor found that all of drought risk levels have decreased normalized difference vegetation index (NDVI) value in very high drought risk area. Decrease in NDVI seems to have lower level more the others. The result of research showed that vegetation condition will be able to detect drought of the area referring to an abnormal rainfall quantity during the year 1994 and it shows decrease in NDVI in January 1995. Copra (2006) found that NDVI of NOAA AVHRR has high correlation with precipitation in water limiting area. The highest NDVI-rainfall correlation associated with one-month time lag shows rainfall event induced vegetation growth in subsequent periods. The NDVI-rainfall correlation was found to be highly influenced by mean rainfall condition and vegetation types. As reported by National Weather Service of USA (2008), since 1980s, NOAA AVHRR satellite data have been used in the National Weather Service established by the Climate Prediction Center (CPC), known at the time as the Climate Analysis Center (CAC). The CPC is the best known United States climate forecasts based on El Niño and La Niña conditions in the tropical Pacific.

The general objective of this study was to develop a new method of agricultural drought assessment by using NOAA AVHRR and weighting analysis of bio-physic factor. Results of this study is expected to provide an alternative approach to assess vulnerability of drought areas. Hence, the spatial information of drought area can be used for preventing drought occured in the future more wisely and well planned.

MATERIALS AND METHODS

The study was conducted at Upper Brantas Watershed, East Java. The area is known as a rice production center in which irrigated land as well as rainfed agriculture is easily found. Based on rainfall data from Perum Jasa Tirta I (2001) and NASA-TRMM (2011), this area was affected by drought in recent years, such as in 1972, 1977, 1982, 1997, and 2002.

The Upper Brantas Watershed covers Malang, Blitar, Tulungagung, and Trenggalek Districts. The study area is around 5,400 km^2, situated at 111°31'-112°55' East and 7°50'-8°15' South, as shown in Figure 1.

Fig. 1. Situation map of study area in Brantas Watershed, Indonesia.

Data used for this study were NOAA AVHRR. Based on earlier researches, NOAA-AVHRR is a better choice for multi-temporal VNIR data. Data used were selected one of the clearest data acquired of each month from April 1997 until March 1999. Selection of acquisition satellite data used was based on report that informed drought occurred in 1994 and 1997, the worst during the 20th century, where more than one million ha of farm land were affected (Puterbaugh 1997; FAO 1998; Gathara *et al*. 2006; Badriyah 2010). In addition, rainfall data from 1955 to 2010 from Perum Jasa Tirta I (2001) and NASA-TRMM (2011) were also considered for NOAA AVHRR data selection.

Verification has been done during ground checking of land cover conditions and interviews with farmers and regional officers. Interviews was conducted on 37 respondents to obtain information on drought conditions in 1997. Respondents were selected purposively in the study area that experienced drought based on the results of image analysis to confirm drought conditions from community for research purposes (Nasoetion 1973; Eriyanto 2007).

Method of analysis consisted of three parts: (1) NOAA AVHRR data analysis; (2) weighting factor analysis; and (3) field verification of drought condition. More detail description of the aforementioned techniques and procedures are presented in Figure 2. NOAA AVHRR data were analyzed to get an NDVI range for determining drought condition. The analysis consisted of two parts, namely: (1) fluctuation of multi-temporal NDVI analysis and (2) normal line diagram analysis.

NDVI is simple and has the best dynamic range of any of the indices and the best sensitivity to changes in vegetation cover (Murai 1995; Ray 1995). The index is called normalized because it is divided by the sum of radiances and normalizes somewhat for differences in solar spectral irradiances. Based on radiance measurements in the visible (VIS), near infrared (NIR), it can be used for indicator of intensity of biomass and vegetation condition, and also for

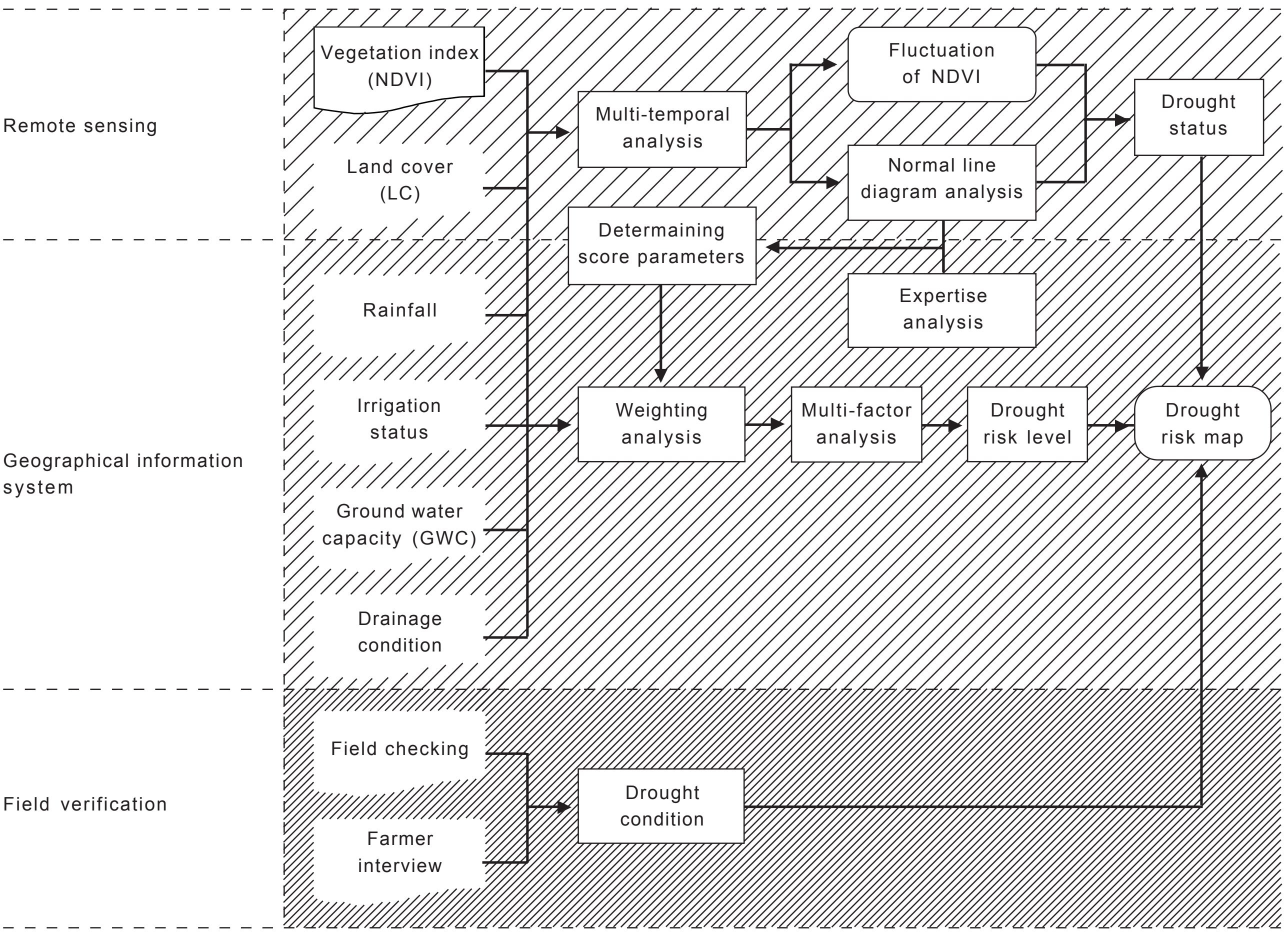

Fig. 2. Flow chart of the method of remote sensing and geographic information system for assessing agricultural drought.

vegetation health (condition) monitoring, including drought detection. The NDVI was calculated as follows (Toselli 1989):

$$\text{NDVI} = \frac{\text{near infrared} - \text{red}}{\text{near infrared} + \text{red}}$$

For NOAA AVHRR, NDVI = (B2 – B1) / (B2 + B1). NDVI values are between -1 and 1. Negative values are sometimes found when the red reflectance is higher than the near infrared as for certain types of dry soils. The NDVI is mainly determined by the difference between the near infrared responses that increase with increasing vegetation in the scene, and the red reflectance which decreases with decreasing vegetation.

For drought assessment, a new method was developed during the study. There were two ways of analyses, i.e. normal line diagram of NDVI and drought status formula. Comparison between NDVI values of 1997 and 1998 using diagram that has normal line was conducted to determine which factors of drought were more significant. Normal line is the condition when NDVI values in both years are equal (x = y) (Fig. 3a). If the NDVI value is located above the normal line, Year II is drier than Year I as normal year. Inversely, if NDVI is below the normal line, Year II is wetter than Year I.

Figure 3b explains an analysis of normal line diagram and tangent function. It provides a comparison between NDVI in 1997 and 1998. The x axis is year 1997 and the y axis is year 1998. It shows that normal line is condition which 1997 had same condition with 1998 (normal year). If NDVI value is above the normal line, condition in 1997 was drier than that in 1998. If the NDVI value is below the normal line, the condition in 1997 was wetter than that in 1998. Comparison can also be made using tangent function to the x axes, by drawing line from the intersection of x and y axes to coordinates of an NDVI point. Normal line is Tg $\alpha = 1$, where α = NDVI value. If $\alpha = 45$, then x and y are normal, $\alpha > 45$ means x is drier, while $\alpha < 45$ indicates y is drier.

Drought status was analyzed using assumption that May to August 1997 had constant value of NDVI in wet season, and in September 1997 the NDVI started to decrease until November 1997. This trend was also happened in 1998. Based on that condition, the drop of NDVI between 1997 and 1998 could be compared to see the condition of drought in 1997. Mathematically it can be expressed as follows:

$$\text{Drought status} = \frac{\text{Ave(NDVI May to Aug)NY-Ave(NDVI Sep to Nov)DY}}{\text{Ave(NDVI May to Aug)NY}}$$

where Ave(NDVI Sep to Nov) DY is average NDVI in September to November (dry season) in drought year and Ave(NDVI May to Aug) NY is average of NDVI from May to August (wet season) in normal year

Weighting analysis was used to assess drought influencing factors and to get a map of drought risk level. Nualchachawee and Hung *in* Prathumchai (1999) noted that no one map layer is enough to make

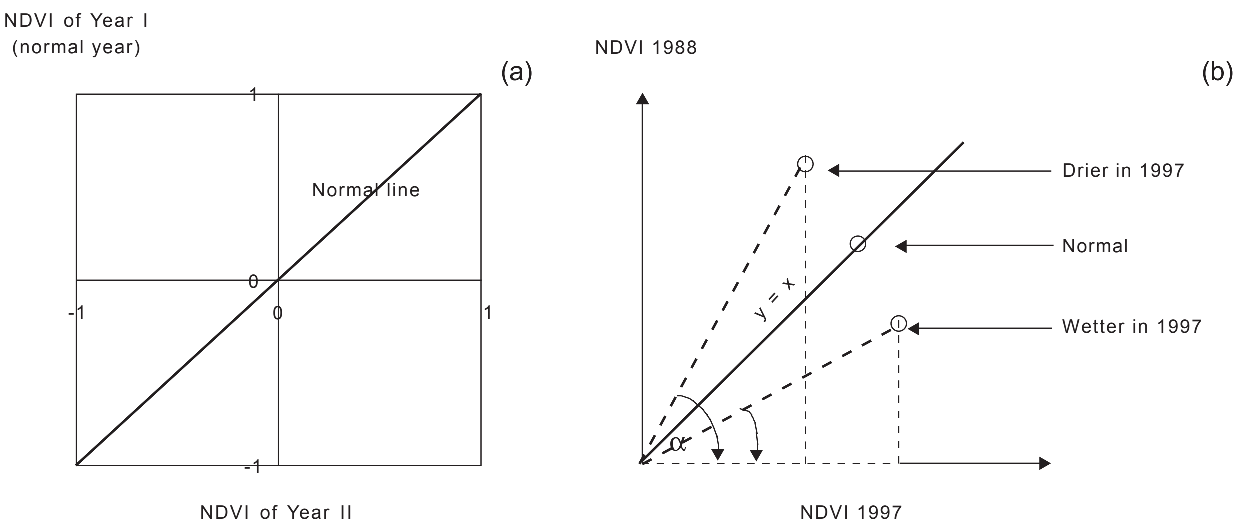

Fig. 3. Diagram to identify normalized difference vegetation index (NDVI) condition; (a) normal line , (b) analysis of the normal line diagram and tangent function.

a decision. The problem can be solved in combining each parameter used by rating procedures, as follows:

- Each factor is rated on separate interval scales;
- A multiplier, usually identified as an importance weight is assigned for each factor;
- The rating for each type is multiplied by the weight for the factor;
- The sum of the products of the ratings is multiplied by the respective weights for each factor.
- Finally, the suitability rating for a particular region is the sum of the multiple rating, or in mathematical terms, as follows:

$$\text{Rating} = w_1r_1 + w_2r_2 + \ldots + w_nr_n$$

where w is weight and r is rating. The weighted parameters are provided in Table 1. The score was given based on the NDVI response in each factor and condition in field as presented in Table 2.

Rainfall is the most important factor that affects drought. Besides being used to determine drought year that has occurred, rainfall data were used to select satellite data used. Rainfall data from 1955 to 2010 in Figure 4 shows that year 1997 had the lowest annual rainfall compared with year after that. Monthly rainfalls in 1997 were also low (Fig. 5). Therefore, the 1997 data were used in this study as they represent drought year.

Table 2. Scoring of drought level.

Drought level	Value
High	0.746-1.000
Moderate	0.582-0.745
Low	0.257-0.581
Very low	0.000-0.256

RESULTS AND DISCUSSION

This analysis was focused on agricultural area (paddy fields and other agriculture). Multi-factor analysis has been identified by observing characters of NDVI to various drought parameters such as rainfall, irrigation, soil drainage, and groundwater capacity, found in several locations in study site. The analysis was done to investigate which factors have more influence on drought conditions based on NDVI. Observations on these parameters to NDVI changes in normal and drought years indicate the factors that influence

Table 1. Parameters and weighting system to assess drought risk area in Upper Brantas Watershed, East Java.

Parameter	Criteria	Weight	Score
Rainfall pattern	C	0.30	1.00
	F		0.85
	G		0.65
	H		0.50
	I		0.40
	J		0.30
	L		0.15
	M		0.00
Irrigation status	Non-irrigated area	0.25	1.00
	Irrigated area		0.00
Groundwater capacity	Poorly productive aquifer	0.20	1.00
	Moderately productive aquifer		0.50
	Highly productive aquifer		0.00
Soil drainage	Excessively drained	0.15	1.00
	Somewhat excessively drained		0.85
	Well drained		0.65
	Moderately well drained		0.50
	Somewhat poorly drained		0.35
	Poorly drained		0.15
	Very poorly drained		0.00
Land cover	Village/urban area	0.10	1.00
	Paddy fields		0.75
	Other agriculture (dryland and upland)		0.50
	Forest2 (shrub and bush)		0.25
	Forest1		0.00

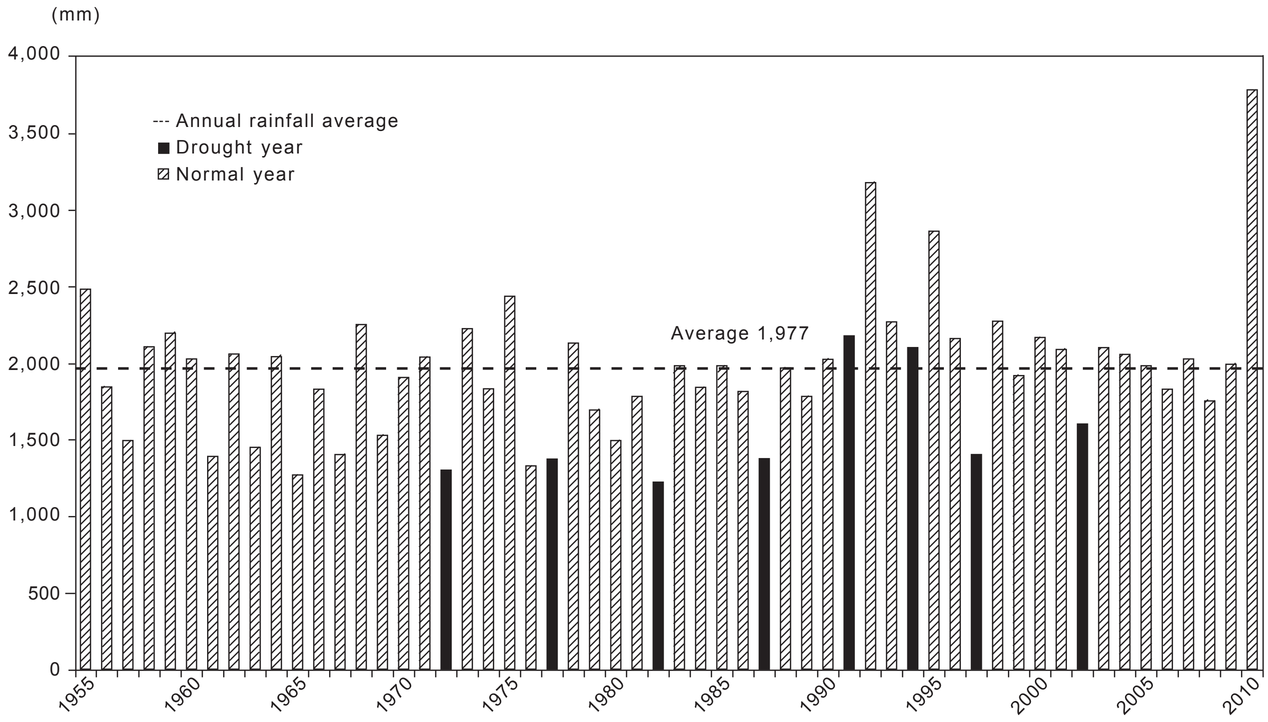

Fig. 4. Annual rainfall of Brantas area, 1955-2010 (Perum Jasa Tirta I 2001; NASA-TRMM 2011).

drought. They will be considered to determine score of each factor based on expert knowledge for weighting analysis.

Analysis of changes in NDVI values was conducted to determine which factors most affecting drought compared to other factors. The analysis of NDVI provided in the next paragraph has been through consideration from field's condition and character of each factor. Water supply was considered as a factor that was more influence than other factors. Rainfall was more influence to NDVI changes followed by irrigation and ground water capacity. The next factor should be considered was physical condition. Soil drainage was also important. If the physical condition did not support crop requirement, then water supply would be ineffective. The last factor was land cover. How human use the area was also considered as factor influencing drought.

Change in NDVI on different monthly rainfall patterns is illustrated in Figure 6. It shows that the NDVI values slightly increases when the monthly rainfall increases. But NDVI is not suddenly decreasing when rainfall decreases. It indicates that the condition is dry because of less water availability.

According to the result presented in Figure 7, irrigated area had higher NDVI during the dry season of 1997, but during the dry season of 1998, the NDVI value was lower than that of non-irrigated area. It can be explained that in drought year, irrigation in this area is adequate. In normal year (1998), non-irrigated area had NDVI value higher than that in irrigated area, but the NDVI value of irrigated area was similar with NDVI value in drought year. It shows that irrigated area is not affected by drought. The NDVI value in this area is more stable than that in non-irrigated area. The high NDVI value of non-irrigated area during the dry season in normal year indicates that water supply in the area in drought season is sufficient by rain.

Groundwater capacity is also important for supplying water during dry season. Based on Directorate of Water Management guide book (Direktorat Pengelolaan Air 2007), ground water can be used as suplesi for irrigation during the wet season (WS) and the first dry season (DS1) when water supply decreases in both rainfed and dryland. For first and second dry season, groundwater is generally used as main water resource. Besides that, local farmers usually use groundwater as a source of irrigation using a pump during the dry season. Therefore, groundwater availability factor should be considered as one in weighting.

The results of analysis showed that high groundwater capacity area had higher NDVI value during dry season in drought year (Fig. 8). In fact, in dry season, groundwater is very important for irrigation

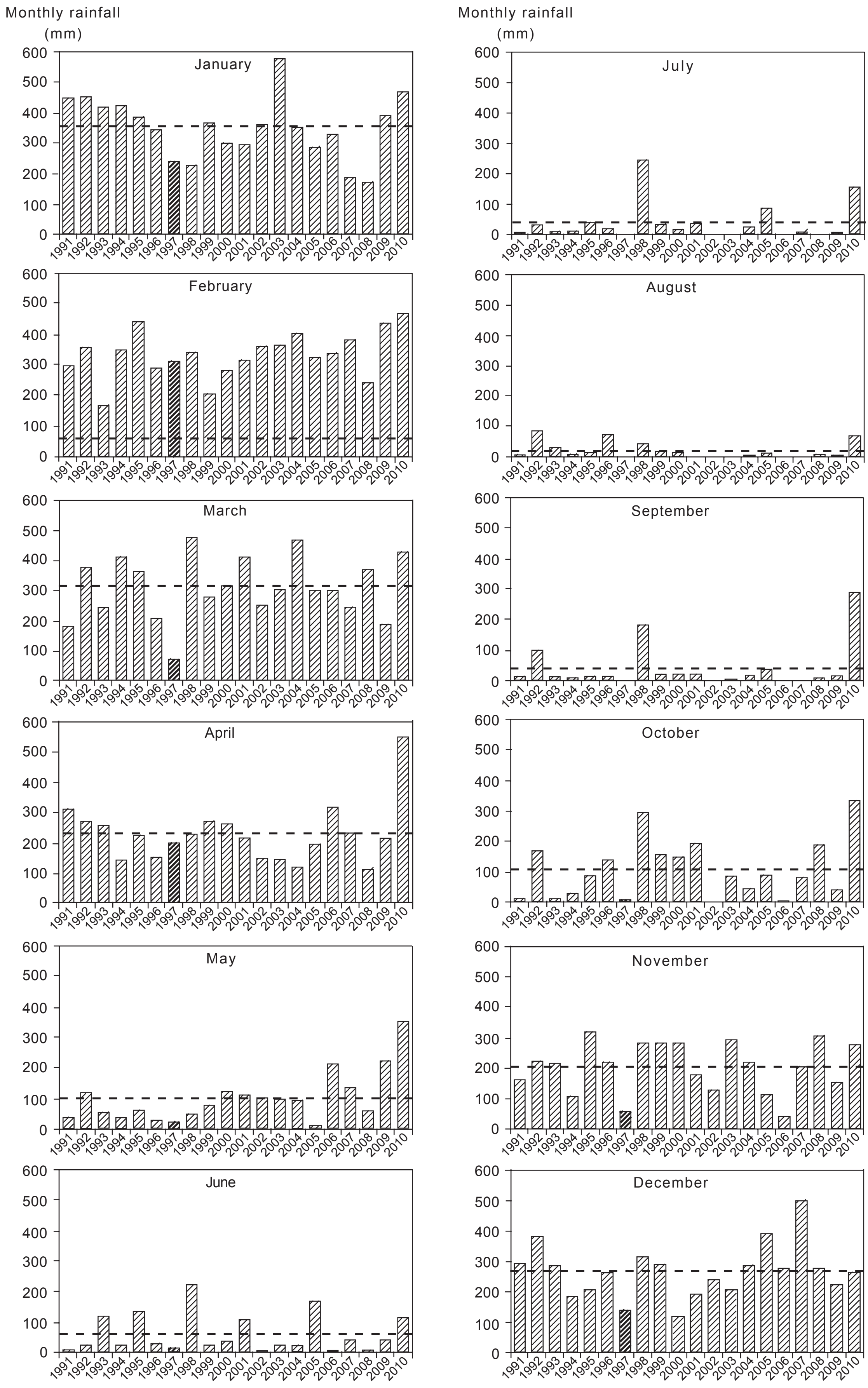

Fig. 5. Monthly rainfall in Brantas Watershed during 1991-2010 (Perum Jasa Tirta I 2001; NASA-TRMM 2011).

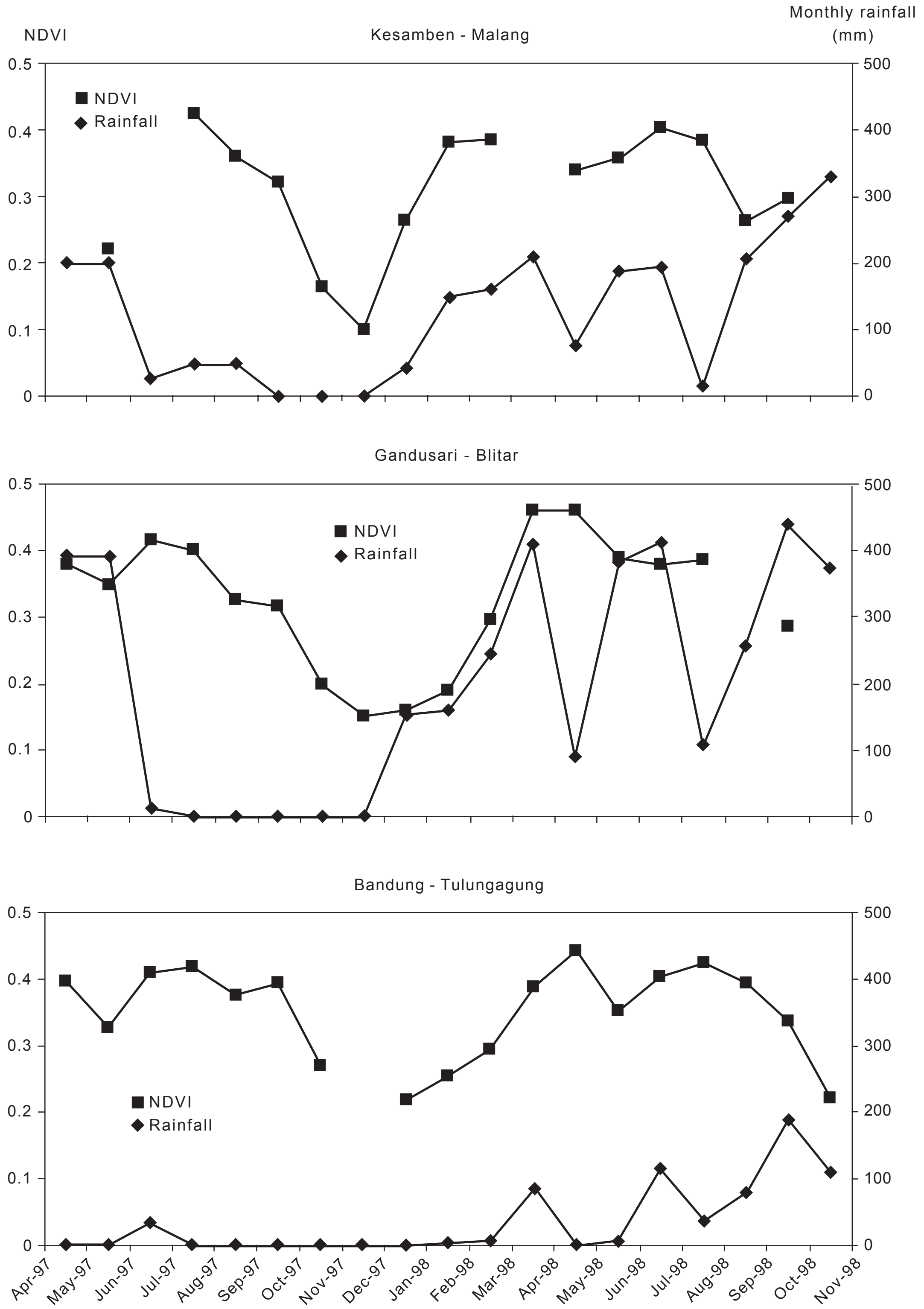

Fig. 6. Change in normalized difference vegetation index (NDVI) on some monthly rainfall conditions in Upper Brantas Watershed, East Java, 1997-1998.

using pump when water from canal is not available. It means that groundwater capacity can reduce drought when the farmers or government invest pump facility in the area. The result showed that NDVI values were almost similar during wet season, but they decreased in normal year.

Soil drainage is a physical factor that influences drought. Drainage classes provide a guide to the

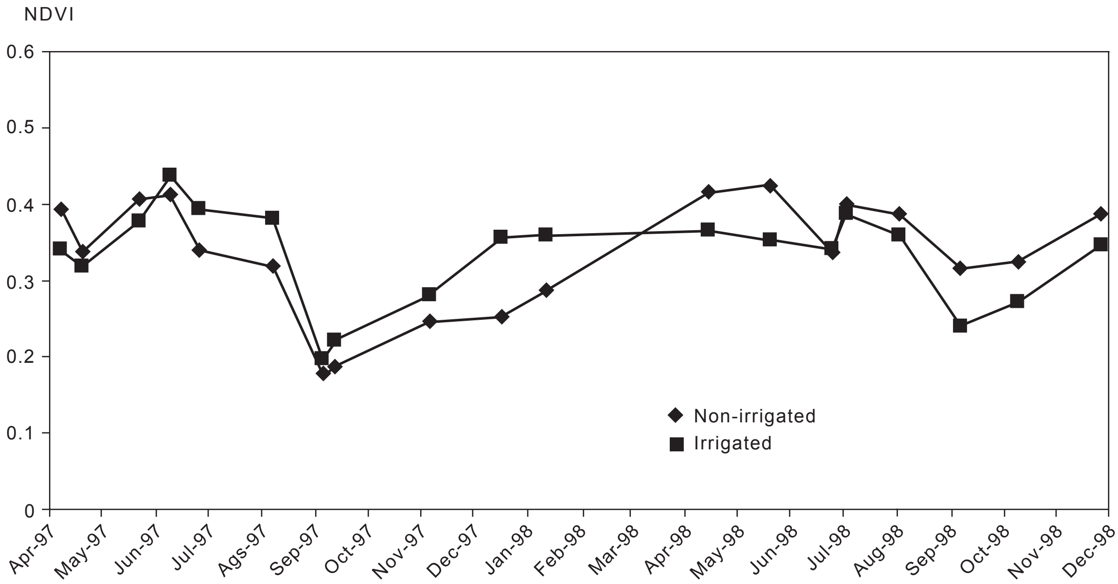

Fig. 7. Change in normalized difference vegetation index (NDVI) on different status of irrigation in Upper Brantas Watershed, East Java, 1997-1998.

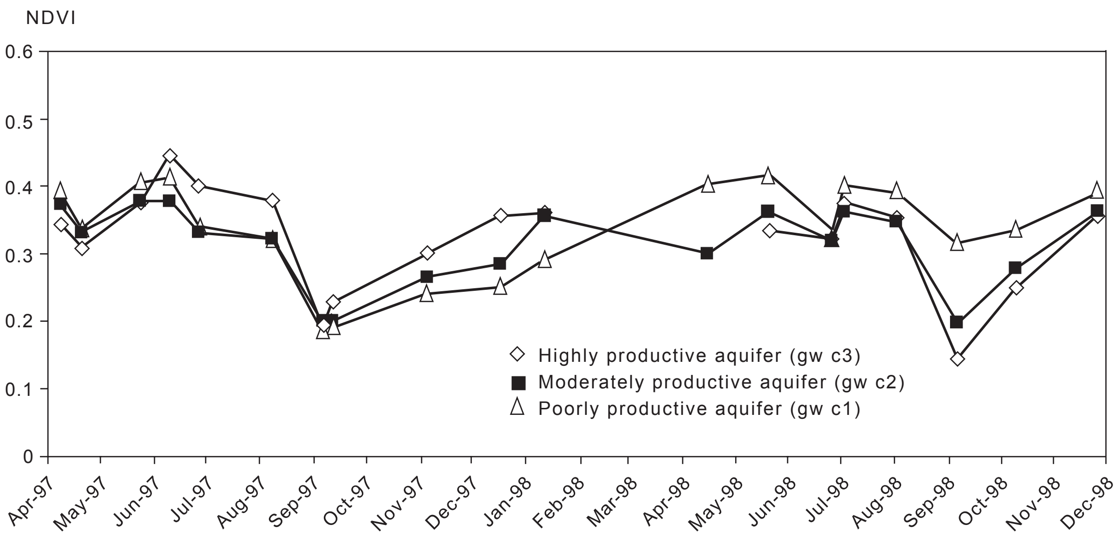

Fig. 8. Changes in normalized difference vegetation index (NDVI) based on different groundwater capacities in Upper Brantas Watershed, East Java, 1997-1998.

limitations and potentials of the soil for crops and forestry. The class roughly indicates the degree, frequency, and duration of wetness (CTECO 2010). The analysis of changes in NDVI values showed no difference in this factor. Level of soil drainage affected water availability in dry season. However, based on analysis of NDVI values, soil drainage influenced vegetation condition, but it showed no difference in each drainage class. For that, this factor was weighted lower than the other factors (Fig. 9).

The average of NDVI value in each region that was taken based on land cover types showed that NDVI decreased during the dry season of 1997 and 1998 (Fig. 10). Comparing with the decreasing NDVI during wet season, the graphic shows that the NDVI condition in 1997 was similar with that in 1998. Meanwhile, NDVI values extremely decreased during September 1997 to October 1997. This period was indicated as drought. But in the dry season of 1998 as normal year, NDVI values slightly decreased. This means that the

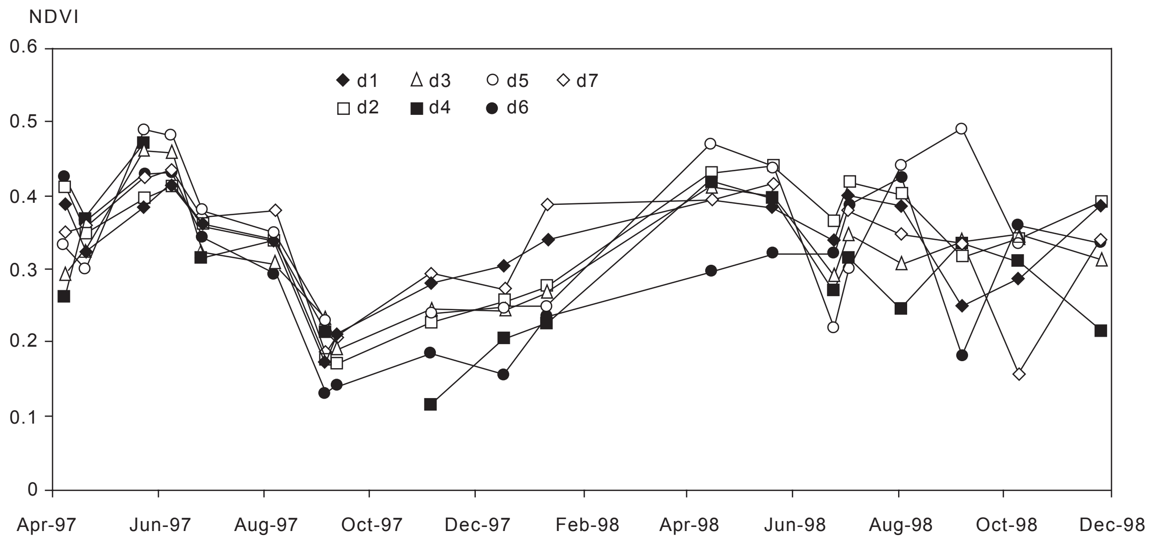

Fig. 9. Change in normalized difference vegetation index (NDVI) on different drainage classes in Brantas Watershed, East Java, 1997-1998.

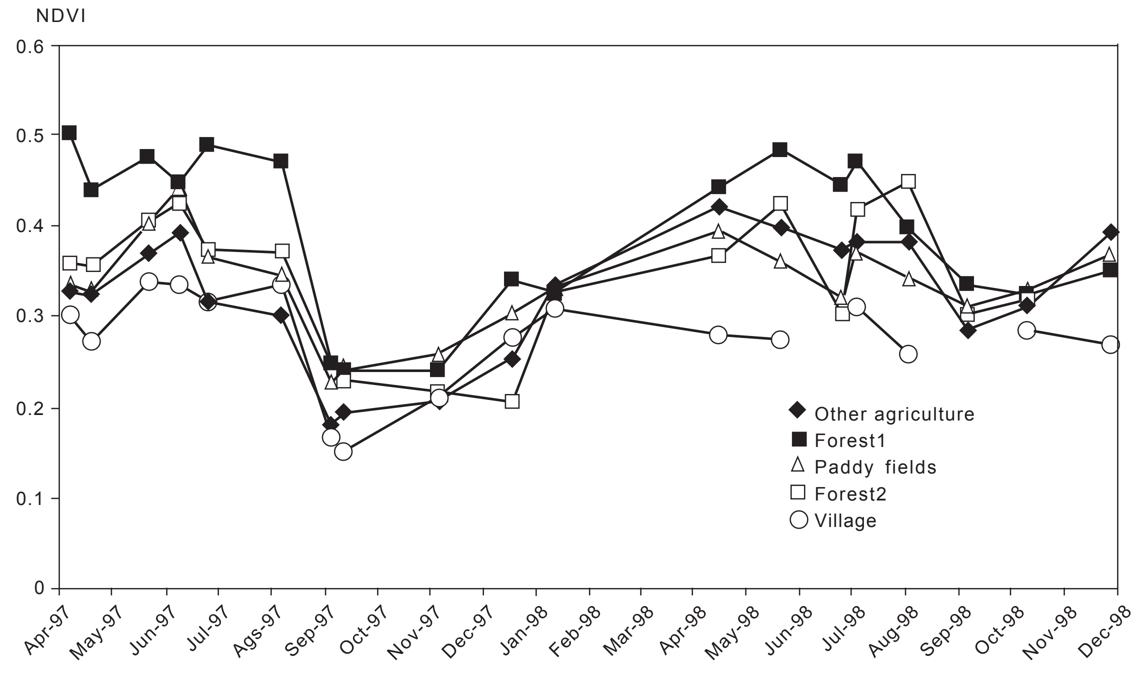

Fig. 10. Change in normalized difference vegetation index (NDVI) on different land use types in Brantas Watershed, East Java, 1997-1998.

condition during the dry season of 1997 was drier than that in 1998. Forest had higher NDVI during the wet season of 1997 and 1998. The NDVI of village land cover type was almost constant, except in the dry season of 1997. The analysis showed that each type of land uses had different responses to drought, indicated by the changes in NDVI values. This is because forest has more tree vegetation that can save water and the vegetation is more survival during drought. The second forest that contains bush and schrub is easy to respond to drought shown by the lower NDVI. Likewise, on food crops on agricultural land or paddy field.

Comparison of NDVI character of some overlaid drought factors by using normal line diagram is provided in Figure 11. Linear line (y = x) is assumed that NDVI is in normal condition. If NDVI value is in normal line, it means that NDVI value in 1997 was similar with that in 1998. If NDVI is above the normal line, it means that condition in 1997 (as x axis), due to decreasing rainfall, was drier than that in 1998 (y axis). If NDVI is below the line, condition in 1997 was wetter than that in 1998.

Using similar comparison by normal line diagram, parameters assumed influencing drought showed different trends. Non-irrigated area was affected by drought, except area that had high rainfall (rainfall pattern M). It can be described by the NDVI value located near the normal line. The irrigated area had NDVI values in surround the normal line in the dry season, except the area with low ground water capacity which had lower NDVI values in 1997. The area with high productivity of ground water capacity had NDVI values located near the normal line. Low ground water capacity area has NDVI value above the normal line. The NDVI values of all drainage types in

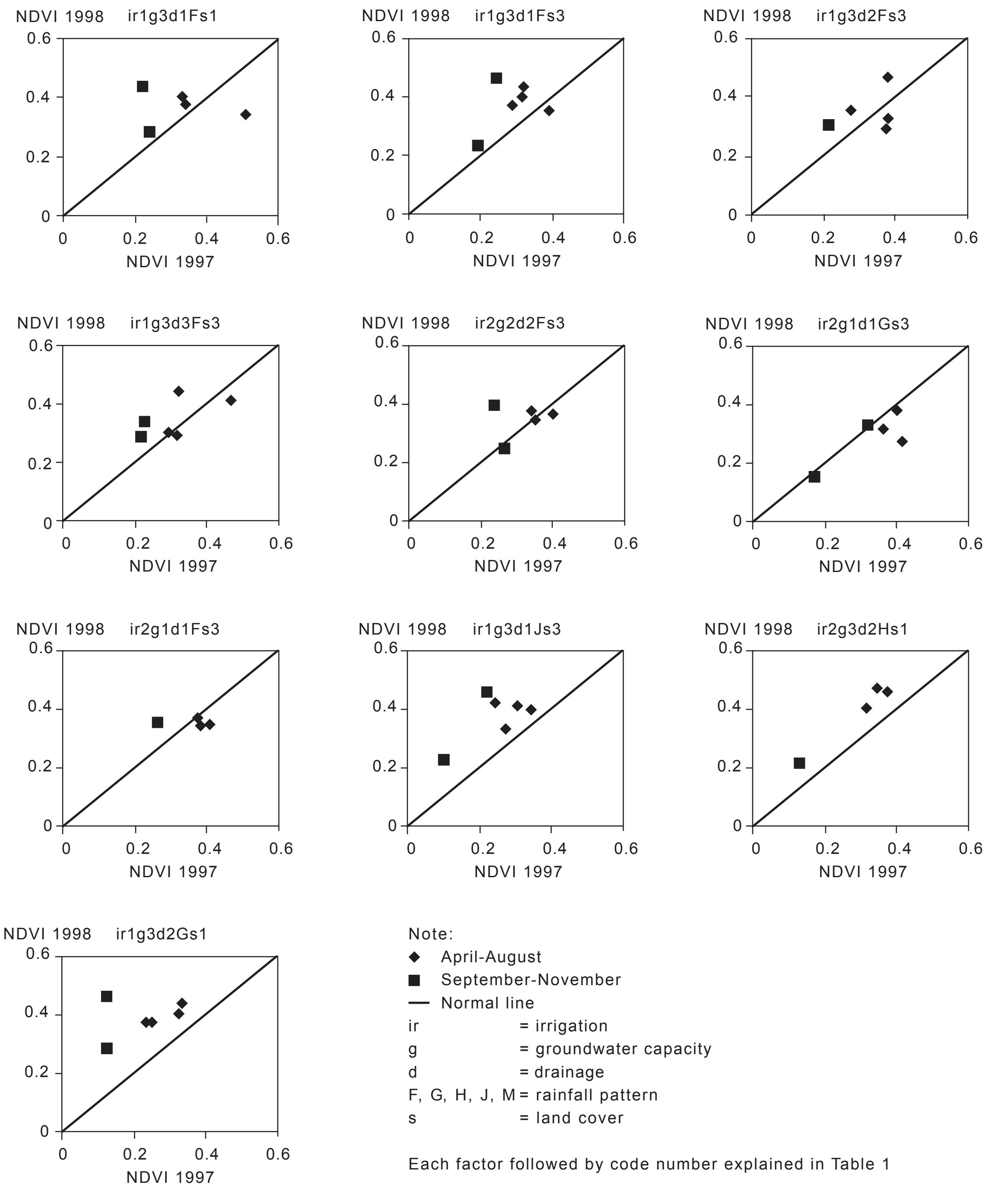

Fig. 11. Comparison between normalized difference vegetation index (NDVI) in 1997 and 1998 in Upper Brantas Watershed, East Java.

the dry season of 1997 were lower than that in 1998. Each land cover also showed different patterns. All NDVI values of other agriculture were above the normal line. NDVI of forest1 was near the normal line, while paddy fields, forest2 and village had NDVI values above the normal line, in and below it. This phenomenon indicates that other agriculture, paddy and village are affected by drought. Forest1 is almost not affected.

Drought Risk Map in the Study Area

Drought risk map produced by overlaying some factors influencing drought is shown in Figure 12. It also considered each factor based on the differences in NDVI fluctuations in drought and normal years, and conditions in fields.

Comparing with drought risk map based on climate data only (Fig. 13), the drought risk map produced by this study described more detail drought risk area. Verification had been done by interview with 37 respondents of farmers and regional officers. They were taken purposively in study area that experienced drought based on the results of image analysis to confirm the map result to drought conditions in 1997. Purposive sampling is a technique of determining sample for a particular purpose only. For research purposes, selection of respondents was based on their knowledge about the condition of drought and people who live in the area in 1997. According to Nasoetion (1973), Patton (1990), and Eriyanto (2007), this technique can be scientifically acceptable to verify the analysis results of a study. The accuracy of the map produced by this study was 59.45% comparied by field check data. It was higher 23.73% than drought risk map based on climate data only.

Comparison of Drop of Normalized Difference Vegetation Index with Drought Risk Map

The result of NDVI and other physical parameter comparison (Table 3) illustrates increasing drought risk (DR) level follow drought status (DS). The relation between DS and DR level was calculated from average DS collected from masking of each DR region. The result showed that increasing DS level was significantly associated with DR level. The determination coefficient was computed at 85% for NOAA AVHRR. This means that NDVI analysis combined

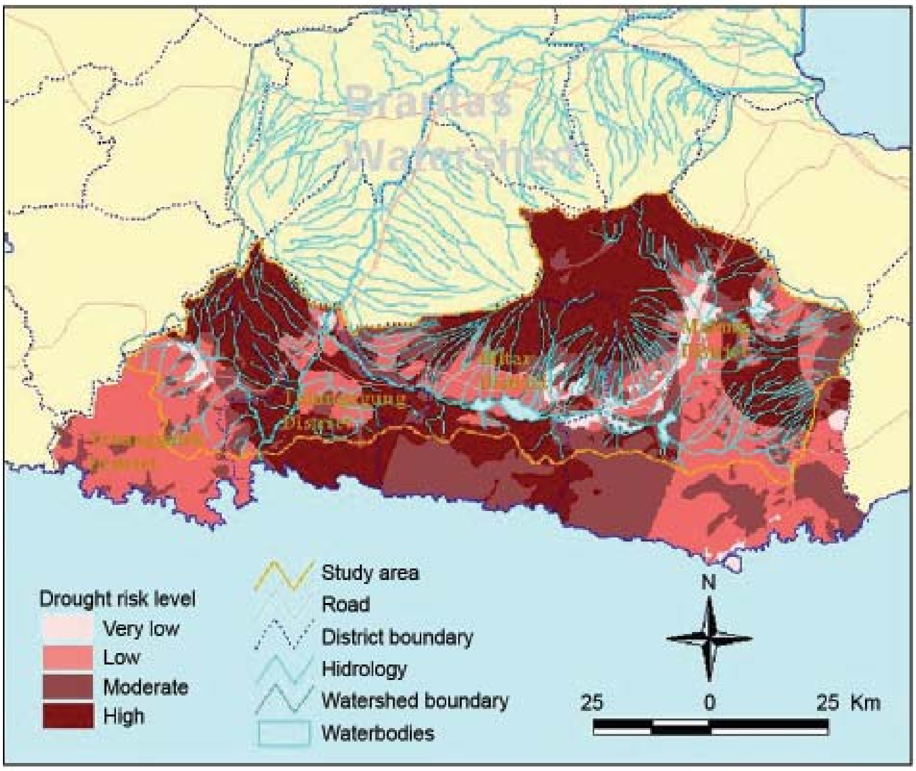

Fig. 12. Drought risk map of Upper Brantas Watershed, East Java.

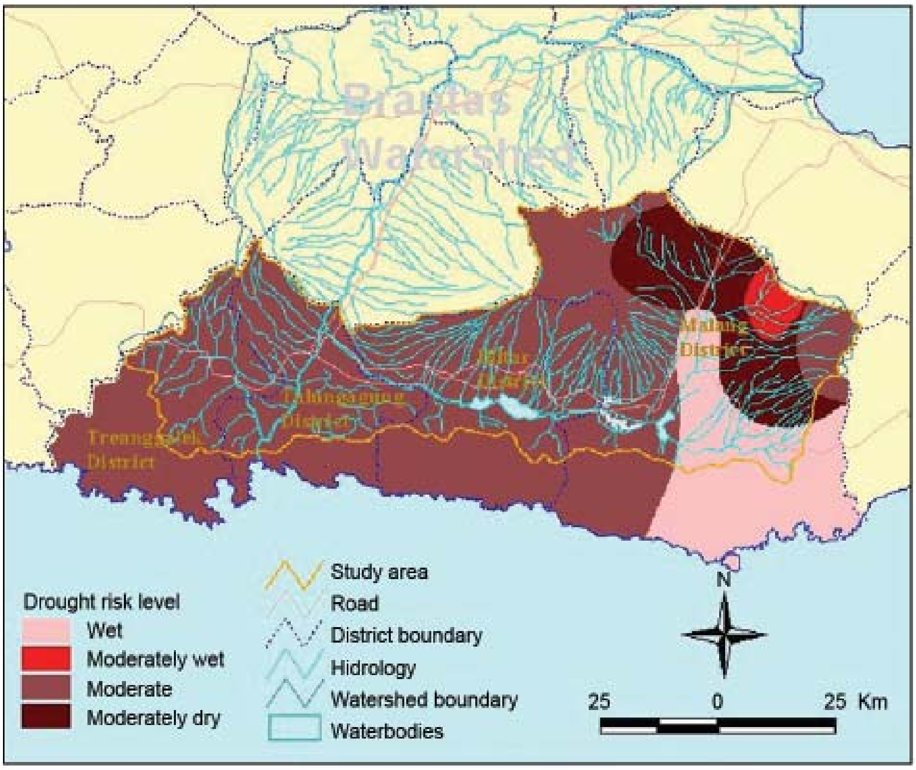

Fig. 13. Drought risk map of Upper Brantas Watershed based on climate data (CSAR 1998).

Table 3. Average of drought status in each drought risk level.

Drought risk level	Average of drought status of NOAA AVHRR
Very low	0.155
Low	0.340
Moderate	0.354
High	0.472

with other parameters such as rainfall data, irrigation condition, groundwater capacity, drainage, and land use can be used for drought monitoring and assessment for year 1997 in Brantas Watershed, Indonesia.

CONCLUSION

Drought assessment using temporal NDVI change and normal line diagram of NDVI analysis of drought factors, such as rainfall, irrigation condition, drainage, groundwater capacity and land use showed significant influence on NDVI character. Thus, they can also justify agricultural drought condition.

Risk assessment method developed using weighting analysis based on expert knowledge and determined based on important significant factors of drought produced a satisfactory drought risk map of study area. The accuracy of map produced was 59.45% comparing with field check data, and higher 23.73% than drought risk map based on single climate data. Accuracy of drought risk map as evaluated by comparing drought status and drought risk showed satisfactory result. It gave a high positive correlation with $R^2 = 0.85$ by using NOAA AVHRR data.

Methods developed in this study can be used to create a time series map of drought status by using remote sensing data. It can show historically drought experienced in Brantas Watershed. The results of weighting analysis on drought influenced factors can be used to create a drought risk map. Combination of those maps can show spatially the vulnarable area of drought. Therefore, the information obtained can be used as a reference to make recommendations on disaster prevention in Brantas Watershed.

REFERENCES

Badriyah, S. 2010. Developments regarding international climate change. Climate Watch Update Vol. 2, August 2010. Institute for Essential Services Reform (IESR).

Copra, P. 2006. Drought Risk Assessment Using Remote Sensing and GIS: A case study of Gujarat. Thesis of Indian Institute of Remote Sensing (IIRS), Dehradun, India, and International

Institute for Geo-Information Science and Earth Observation, Enschede, the Netherlands.

CTECO (Connecticut Environmental Condition Online). 2010. Soil Drainage Class. Connecticut Department of Environment and University of Connecticut, USA.

Datt, B. 1999. Visible/near infrared reflectance and chlorophyll content in *Eucalyptus* leaves. Int. J. Remote Sensing 20(14): 2741-2759.

Direktorat Pengelolaan Air. 2007. Pedoman Teknis Pengembangan Irigasi Air Tanah Dalam. Ditjen Pengelolaan Lahan dan Air, Jakarta.

Eriyanto. 2007. Teknik Sampling Analisis Opini Publik. PT LKiS Pelangi Aksara, Yogyakarta. hlm. 250-254.

FAO (Food and Agriculture Organization). 1998. Drought and financial crisis leave Indonesia facing record food deficit. http://www.fao.org/english/newsroom/global/GW9810-e.htm. (09 April 2010).

Gathara, S.T., L.G. Gringof, E. Mersha, K.C. Sinha-Ray, and P. Spasov. 2006. World Meteorological Organization: Impacts of desertification and drought and other extreme meteorological events. Commission for Agricultural Meteorology Report No. 101.

Gomarasca, M.A., P.A. Brivio, and F. Pagnoni. 1993. One century of land use changes in the metropolitan area of Milan (Italy). Int. J. Remote Sensing 14(20): 211-223.

Liu, W.T. and F.N. Kogan. 1996. Monitoring regional drought using the vegetation condition index. Int. J. Remote Sensing 17(14): 2761-2782.

Makmur, E. 2009. Drought assessment over Indonesia related to El Nino and SSTA Indonesia. Inter-Regional Workshop on Indices and Early Warning Systems for Drought, Lincoln, Nebraska, 8 November 2009. http://www.wamis.org/agm/meetings/wies09/S53-Erwin.pdf. (09 April 2010).

Murai, S. 1995. Remote Sensing Note. Japan Association on Remote Sensing, Tokyo, Japan.

NASA-TRMM. 2011. Goddard Earth Science Data and Information Service Center: TRMM - Tropical Raifall Measuring Mission. http://trmm.gsfc. nasa.gov/. (17 April 2011).

Nasoetion, A.H. 1973. Some Statistical Principles and Procedures. Agricultural Development Council, Singapore. 43 pp.

National Weather Service of USA. 2008. Who We Are. Climate Prediction Center (CPC). NOAA National Weather Service, National Center for Environment Prediction, Maryland, USA.

Pasandaran, E. dan Hermanto. 1997. Pengelolaan sistem irigasi hemat air untuk mempertahankan swasembada beras. *Dalam* G. Kurnia (Ed). Hemat Air Irigasi. Kebijakan, Teknik, Pengelolaan, dan Sosial Budaya. Pusat Dinamika Pembangunan Universitas Padjadjaran, Bandung, Indonesia.

Patton, M.Q. 1990. Qualitative Evaluation and Research Methods. 2nd Ed. Sage Publications, Newbury Park, CA. p.?

Perum Jasa Tirta I. 2001. Data Hidrologi 2000. Perum Jasa Tirta I, Malang, Indonesia.

Prathumchai, K. 1999. Assessment of Drought Risk Using Remote Sensing and GIS: A case study in Lop Buri Province, Thailand. Asian Institute of Technology, Bangkok, Thailand.

Prathumchai, K., K. Honda, and K. Nualchawee. 2001. Drought risk evaluation using remote sensing and GIS: A case study in Lop Buri Province. Proceedings of the 22nd Asian Conference of Remote Sensing, Singapore, 5-9 November 2001.

Puslittan (Pusat Penelitian Tanah). 1989. Laporan Akhir Survei dan Pemetaan Tanah Semi Detail, Daerah Lahan Kering/Kritis DAS Brantas Hulu Propinsi Jawa Timur. Pusat Penelitian Tanah, Bogor, Indonesia.

Puterbaugh, T. 1997. World Agricultural Production. Foreign Agricultural Service (FAS) USDA. http://www.fas.usda.gov/WAP/circular/1997. (29 October 2000).

Ray, T.W. 1995. Vegetation in Remote Sensing FAQS. Er Mapping Applications. Earth Resources Mapping Pty. Ltd., Perth, West Australia.

Saint, G. 1996. Land cover mapping for global change research. *In* G. D'Sonza, A.S. Belward, and J.P. Malingreau (Eds.). Advances in the Use of NOAA-AVHRR Data for Land Applications. Institute for Remote Sensing Applications, ISPRA, Verese, Italy.

Thiruvengadachari, S., A.T. Jeyseelan, J. Harikishan, and P.V. Krishna-Rao. 1991. Satellite surveillance of agricultural drought conditions in India - How useful is vegetation index for drought monitoring? *In* S. Murai (Ed.). Applications of Remote Sensing in Asia and Oceania - Environmental Change Monitoring. Asian Association on Remote Sensing, Tokyo, Japan.

Toselli, F. 1989. Applications of remote sensing to agrometeorology. Proceedings of a course held at the Joint Research Centre of the Commission of the European Communities in the Framework of the ISPRA-Courses, ISPRA, Verese, Italy.

Tripathy, G.K., T.K. Ghosh, and S.D. Shah. 1996. Monitoring of desertification process in Karnataka State of India using multi-temporal remote sensing and ancillary information using GIS. Int. J. Remote Sensing 17(12): 2243-2257.

Verbila, D.L. 1995. Satellite Remote Sensing of Natural Resources. Lewis Publ., Boca Raton, Florida.

Wibisono, B.K. 2010. BLH Terapkan Agroforestry Lindungi Mata Air Brantas. Antara News.com. (6 April 2010).