Climate-based crop pattern determination using Standard Precipitation Index (SPI) and the Oldeman classification in Sangiran Site

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Abstract. Sangiran Site is dominated by rainfed field. Climate parameters, especially rain intensity affects crop patterns. Farmers strongly depend on rain intensity to support productivity thus they need climate-based crop patterns. Sangiran Site is prone to drought hazard since the region has a limited access to groundwater, which is hence by deep well in the region. Drought becomes the main threat to agriculture within Sangiran. This study aims to analyse meteorological drought and crop pattern determination using the SPI and the Oldeman classification respectively. Rainfall data is derived from multi temporal CHIRPS data. A monthly time series with thirty consecutive years (1988–2017) was used to calculate the annual SPI. The annual SPI help to determine crop patterns which is suitable for the region. The results of the study show that Sangiran Site has monsoonal rainfall with one peak of dry season, and one peak of wet season. Rainfed field is at the highest risk when drought lasts for above four months. Climate based crop patterns with the Oldeman classification indicate that Sangiran Site is classified into type C2 which is adequate for two times palawija crops and one time paddy crops.

1. Introduction

Sangiran Site (Figure 1) has been recognized by UNESCO due to significant discovery of Homo erectus fossils. It is located in Sragen Regency, Central Java Province. The region has total area of 64 square kilometer. The topography of Sangiran is generally hilly in the center and southern part. An seasonal river flows through Sangiran Site. thus the region has limited access to groundwater. The landuse in Sangiran Site is dominated with rainfed agriculture.

Due to the limited access to groundwater and surface rivers, farmers strongly depend on rainfall to support agriculture. There are few number of farmers have access to rivers since they are small canals which flow in the eastern side of Sangiran Site where the topography is generally flat. The lack of water to support irrigation puts the region to be prone to drought.

Drought is as a disaster which frequently occurs in Sangiran Site, therefore it needs to be intervened [1]. The extreme droughts happened in 1982/1983, 1986/1987, 1991/1992, 1997/1998, 2002/2003, 2009/2010 and it affected the environment in Indonesia, such as agriculture, water resource, etc [2]. Drought is categorized as hazard where severe drought has an effect on water reserves thus impose threats and damages to social, economic, and environmental [3 – 5]. The definition of drought varies
among researchers and becomes a challenge for them [6]. Because it affects many sectors, drought can be seen from many perspectives and drought can be categorized into meteorological drought, agricultural drought, hydrological drought, and socio-economical drought. Meteorological drought is a phenomenon caused by shortage of rainfall, which represents rainfall intensity is below the long-term average of rainfall [7].

Figure 1. Map of Sangiran Site

Drought monitoring and early warning system requires a comprehensive approach thus the monitoring can provide useful informations regarding drought forecasting and patterns [8]. An effective way is to use the drought indices, such as the Standard Precipitation Index (SPI), which is crucial to detect drought since the index is a comprehensive system and related to climate and the environment [9].

Standardized Precipitation Index (SPI) is the idea of McKee, Doeken, and Kleist in 1993 which is aimed to detect drought with rain intensity as the parameter. The SPI is used to forecast dry periods and wet periods. Positive value of SPI shows that the rainfall intensity is above long-term average, meanwhile negative value shows that the rainfall intensity is below long-term average [10].

| SPI Value | Classification         |
|-----------|------------------------|
| ≥ 2.0     | Extremely wet          |
| 1.5 – 1.99| Very wet               |
| 1.0 – 1.49| Moderately wet         |
| (- 0.99) – 0.99 | Near normal         |
| (- 1.0) – (- 1.49) | Moderately dry        |
| (- 1.5) – (- 1.99) | Severely dry            |
| ≤ (- 2)   | Extremely dry          |
The SPI drought index is the most commonly used precipitation drought index. The SPI is used to detect long-term drought trends, approximately 30 to 100 years. The SPI also detects the duration and intensity of drought. The advantage of the SPI is inheritably normalized because the SPI value has the same frequency to be applied on every location [11]. The SPI is flexible due to multi temporal data, thus can be used as an drought early warning system. The explanation indicates that this method has many functions so that these study aims are to analyze the rainfall pattern in Sangiran Site, analyze the drought using SPI, and analyze the agroclimatic zone using oldeman classification.

2. Methods
Rainfall data is derived from Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS). A monthly time series with thirty consecutive years (1988-2017) is used to calculate the SPI. The Annual SPI provides dry and wet period data to determine agroclimate zone based on the Oldeman classification. The Oldeman classification helps farmers to adapt with climate conditions and determine climate based crop patterns.

2.1. CHIRPS data processing (1988 – 2017)
Rainfall basics of CHIRPS are climate data basics which consist of rainfall intensity of land area (ocean is excluded) [12]. The CHIRPS dataset is commonly used to watch meteorological drought with frequent rainfall data series [13]. The CHIRPS rainfall data combines many stations and uses high resolution data thus resulting a better rainfall data [14]. The CHIRPS rainfall data can be accessed at Climate Hazard Group (CHG) website of University of California at Santa Barbara (UCSB) (http://chg.geog.ucsb.edu/data/ chirps/index.html) [13]. The required rainfall data are between year 1988 – 2017. The CHIRPS rainfall data are processed with ArcGIS software to extract data and resulting on rainfall spatial zonation.

2.2. Rainfall data processing
The results of CHIRPS data processing of rainfall data year 1988 – 2017 are six grids of rainfall in Sangiran Site. Every grid resembles monthly rainfall. The monthly rainfall for 30 years of the six grids are processed to obtain information about rainfall in Sangiran Site. The six grids are used to analyse rainfall patterns and trends of Sangiran Site. Analysis of rainfall grid data results on rainfall spatial zonation. This study also interpolates the six points of grid using Krigging method to obtain rainfall spatial zonations. Monthly rainfall year 1988 – 2017 is calculated to know the average value and rainfall pattern. Analysis of rainfall pattern in Sangiran Site uses the three year simple moving average to obtain short-term rainfall pattern. The moving average value is derived from the average calculation of every grid point of rainfall. The average calculation is every 3 years of rainfall data.

The interpolation requires the six grid points which spreads evenly within Sangiran Site thus the results can be smooth and scientifically accurate. The interpolation between rainfall points use annual rainfall average 1988 – 2017 in every grid point of Sangiran Site. Kriging method is used to interpolate because the method has high accuracy [15]

2.3. Drought analysis using the SPI
The SPI is commonly used by researchers to detect meteorological drought [15]. The SPI method uses temporal scale which varies between 30 to 100 years. The principle of the SPI method including standard deviation with a long-term normal distribution data [16]. The input of the SPI method using long-term rainfall data series to calculate water deficit value. The combination of CHIRPS rainfall data and the SPI has a contribution in drought monitoring because it is supported by detailed spatial data and adequate time scale [13].

2.4. The Oldeman Classification
The Oldeman classification lies on the same basis as the Schmidt-Ferguson system, which is rainfall intensity. Wet months and dry months are associated with agriculture in a certain region. The criteria of wet and dry months according to the Oldeman classification:

- Wet month: monthly rainfall average over 200 mm
- Humid month: monthly rainfall average between 100 to 200 mm
- Dry month: monthly rainfall average below 100 mm

The Oldeman classification is based on plant water needs, especially paddy. Rainfall intensity over 200 mm is considered good for paddy water needs, meanwhile 100 mm rainfall is considered good for palawija crops [17].

### Table 2. The Oldeman classification

| Classification | Criteria |
|-----------------|----------|
| A1              | >9 consecutive wet months, and 1 dry month |
| A2              | >9 consecutive wet months, and 2 dry months |
| B1              | 7 – 9 consecutive wet months, and 1 dry month |
| B2              | 7 – 9 consecutive wet months, and 2 – 4 dry months |
| C1              | 5 – 6 consecutive wet months, and 1 dry month |
| C2              | 5 – 6 consecutive wet months, and 2 – 4 dry months |
| C3              | 5 – 6 consecutive wet months, and 5 – 6 dry months |
| D1              | 3 – 4 consecutive wet months, and 1 dry month |
| D2              | 3 – 4 consecutive wet months, and 2 – 4 dry months |
| D3              | 3 – 4 consecutive wet months, and 5 – 6 dry months |
| D4              | 3 – 4 consecutive wet months, and >6 dry months |
| E1              | <3 consecutive wet months, and <2 dry months |
| E2              | <3 consecutive wet months, and 2 – 4 dry months |
| E3              | <3 consecutive wet months, and 5 – 6 dry months |
| E4              | <3 consecutive wet months, and >6 dry months |

3. Results and Discussion

3.1. Rainfall analysis

According to rainfall data processing, Sangiran Site has monsoonal pattern. It is evidenced by the V-shaped curve, with one peak of wet season, which is called unimodal (see Figure 2). A unimodal wet season is a pattern where there is only one rainfall peak with no alternation of humid and dry months within the wet season [18]. Wet season reaches its peak in December, January, and February, and dry season reaches its peak in August. The maximum rainfall intensity is 350 mm/month, the minimum rainfall intensity is below 50 mm/month.
Table 3. Monthly rainfall in Sangiran Site

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|
| 1988 | 361 | 390 | 321 | 118 | 262 | 63  | 29  | 20  | 41   | 208 | 316 | 262 |
| 1989 | 380 | 354 | 238 | 211 | 202 | 266 | 243 | 66  | 39   | 198 | 235 | 239 |
| 1990 | 529 | 275 | 351 | 192 | 157 | 45  | 65  | 46  | 56   | 103 | 281 | 359 |
| 1991 | 372 | 349 | 195 | 162 | 88  | 65  | 28  | 15  | 38   | 40  | 291 | 381 |
| 1992 | 309 | 297 | 315 | 242 | 314 | 47  | 34  | 107 | 123  | 250 | 316 | 293 |
| 1993 | 370 | 237 | 316 | 207 | 176 | 172 | 54  | 11  | 69   | 90  | 222 | 290 |
| 1994 | 325 | 373 | 467 | 149 | 90  | 23  | 20  | 16  | 48   | 45  | 165 | 277 |
| 1995 | 350 | 362 | 317 | 212 | 144 | 256 | 46  | 10  | 45   | 119 | 327 | 250 |
| 1996 | 321 | 322 | 285 | 229 | 35  | 52  | 31  | 101 | 64   | 348 | 239 | 261 |
| 1997 | 162 | 211 | 197 | 178 | 75  | 38  | 26  | 23  | 30   | 28  | 160 | 272 |
| 1998 | 148 | 445 | 361 | 177 | 145 | 190 | 160 | 33  | 59   | 304 | 296 | 277 |
| 1999 | 382 | 273 | 394 | 215 | 110 | 34  | 62  | 26  | 51   | 394 | 287 | 412 |
| 2000 | 332 | 267 | 286 | 349 | 296 | 97  | 41  | 74  | 110  | 223 | 450 | 158 |
| 2001 | 343 | 329 | 238 | 336 | 114 | 219 | 63  | 29  | 111  | 260 | 310 | 198 |
| 2002 | 357 | 322 | 286 | 157 | 107 | 23  | 19  | 14  | 26   | 75  | 272 | 260 |
| 2003 | 313 | 370 | 219 | 71  | 103 | 19  | 17  | 18  | 59   | 170 | 346 | 348 |
| 2004 | 329 | 363 | 400 | 140 | 145 | 96  | 64  | 14  | 36   | 47  | 429 | 381 |
| 2005 | 225 | 195 | 367 | 137 | 70  | 144 | 97  | 28  | 137  | 249 | 218 | 464 |
| 2006 | 385 | 396 | 370 | 266 | 241 | 20  | 17  | 14  | 30   | 30  | 175 | 321 |
| 2007 | 163 | 297 | 410 | 331 | 157 | 68  | 43  | 31  | 26   | 141 | 250 | 539 |
| 2008 | 242 | 465 | 449 | 208 | 67  | 35  | 19  | 41  | 44   | 216 | 345 | 362 |
| 2009 | 347 | 458 | 200 | 200 | 298 | 79  | 36  | 17  | 41   | 47  | 315 | 243 |
| 2010 | 376 | 381 | 395 | 320 | 512 | 151 | 204 | 156 | 384  | 267 | 261 | 362 |
| 2011 | 282 | 270 | 333 | 332 | 199 | 40  | 40  | 11  | 26   | 117 | 354 | 366 |
| 2012 | 375 | 289 | 289 | 191 | 97  | 109 | 19  | 12  | 29   | 150 | 298 | 355 |
| 2013 | 466 | 350 | 343 | 216 | 241 | 292 | 168 | 39  | 32   | 85  | 228 | 329 |
| 2014 | 340 | 297 | 328 | 217 | 161 | 174 | 66  | 21  | 36   | 38  | 283 | 294 |
| 2015 | 302 | 372 | 345 | 259 | 120 | 29  | 17  | 12  | 28   | 24  | 247 | 269 |
| 2016 | 242 | 354 | 320 | 246 | 294 | 336 | 234 | 85  | 369  | 406 | 487 | 315 |
| 2017 | 324 | 350 | 241 | 210 | 133 | 128 | 59  | 9   | 68   | 242 | 515 | 336 |

Criteria:
- Blue: Wet month
- Pink: Dry month
The average annual rainfall at the Sangiran Site is 2,400 mm / year. The six graphs in Figure 2 are the results of rainfall trends analysis that have not shown any fixed patterns or trends in the study area, where the rainfall patterns tend to vary from 1988 until 2017. The peaks and valleys formed do not have a repeating pattern, so they cannot be used to predict or forecast how the characteristics of rainfall pattern in the next period.

Figure 2. Monthly rainfall of point 1,2,3,4,5, and 6 during 1988 – 2017
The highest average annual rainfall reached its peak in 2010 and 2016, such as 3,770 mm/year in 2010 and 3,679 mm/year in 2016, meanwhile annual rainfall’s lowest drop happened in 1997 (1,405 mm/year). The extreme value was strongly influenced by ENSO events. The high annual rainfall in 2010 and 2016 was affected by the influence of La Nina events which happened in the same year. In 1997 there was strong El Nino index which impacted on severe drought. The extreme drought in Sangiran Site is worsened by the topography condition which lacks of groundwater.

Interpolation of rainfall points in the Sangiran Site Area using the kriging method produces zones with 4 scales, namely zones with rainfall of 2,300 - 2,350 mm / year, 2,350 - 2,400 mm / year, 2,400 - 2,450 mm / year, and 2,450 - 2,500 mm / year (Figure 3). The division of classification for each multiple of 50 mm / year is based on monthly publication of the rainfall distribution map by BMKG. The most dominant annual rainfall zone in the Sangiran Region is an area with an annual rainfall of 2,400 - 2,450 mm / year (See Figure 3).
3.2. Drought analysis

The longest drought occurred in June 2002 to August 2003 which lasted for 15 months. This condition causes agriculture drought in the Sangiran Site, considering that the majority of agriculture in this area is rainfed fields. The amount of rain that does not meet the water needs of rice fields in this area causes the quality of agricultural production to decline. The severe drought devastated agriculture productivity since the region’s main landuse is rainfed field.

Table 4. Greater than or Equal to Three Months Duration of Drought Events

| The SPI Drought       | Duration | Moderately Dry | Dry | Very Dry | Extremely Dry |
|-----------------------|----------|----------------|-----|----------|---------------|
| April – June 1991     | 3 months | -              | 2 months | 1 month | -             |
| January 1997 – February 1998 | 13 months | 2 months | 3 months | 3 month | 5 months |
| June 2002 – August 2003 | 15 months | 6 months | 6 months | 1 month | 2 months |
| August 2006 – February 2007 | 7 months | -              | 5 months | 1 month | 1 month |
| July 2015 – February 2016 | 7 months | -              | 7 months | -       | -             |

The effect of El Nino on drought in Sangiran was analyzed using temporal distribution of SOI index values and the phenomenon of drought based on SPI in the Sangiran Area (Table 5). Based on Table 5 it can be concluded that some droughts in Sangiran happened because of El Nino events. Extreme drought which happened during January 1997 to February 1998 affects agriculture and water availability in Sangiran Site. It was influenced by strong El Nino index. In 1997, El Nino is occurred during almost the year, where the peak of strong El Nino event is occurred in June (SOI = -24.1). In 1998, a strong El Nino event (-22 < SOI < -28.5) is occurred during January – April (peak in March) [20]. The drought is detailed into five extremely dry months, three very dry months, three dry months, and two moderately dry months. Drought period during August 2006 to February 2007 was also affected by El Nino. Furthermore, drought period during July 2015 to February 2016 was influenced by strong El Nino which was strong enough to affect rainfall over vast region, including region which has monsoonal pattern such as Jawa, Bali, Nusa Tenggara, Lampung, southern parts of Borneo and Sulawesi.

Table 5. Drought and El Nino Events in Sangiran Site

| Year | Criteria  | Jan | Feb | Mar | Apr | May | June | July | Agst | Sept | Oct | Nov | Dec |
|------|-----------|-----|-----|-----|-----|-----|------|------|------|------|-----|-----|-----|
| 1988 | Drought   |     |     |     |     |     |      |      |      |      |     |     |     |
| 1989 | Drought   |     |     |     |     |     |      |      |      |      |     |     |     |
| 1990 | Drought   |     |     |     |     |     |      |      |      |      |     |     |     |
| 1991 | Drought   |     |     |     |     |     |      |      |      |      |     |     |     |
| 1992 | Drought   |     |     |     |     |     |      |      |      |      |     |     |     |
| 1993 | Drought   |     |     |     |     |     |      |      |      |      |     |     |     |
| 1994 | Drought   |     |     |     |     |     |      |      |      |      |     |     |     |
| 1995 | Drought   |     |     |     |     |     |      |      |      |      |     |     |     |
| 1996 | Drought   |     |     |     |     |     |      |      |      |      |     |     |     |
| 1997 | Drought   |     |     |     |     |     |      |      |      |      |     |     |     |
### 3.3. The Oldeman classification

The Sangiran site according to Oldeman Climate classification is classified into 4 months dry and 6 months wet (See Table 3). The Oldeman rain area is called the agro-climate zone because this
classification considers the order of wet and dry months so that climate classification can be linked to agricultural conditions at the Sangiran site.

The Sangiran site has a diversity of agroclimate zones which includes A2, B2, C2, C3, D3, E4, and four years that are not classified (2008, 2009, 2010, and 2016). Zone A2 is suitable for growing paddy throughout the year, but the production could be not optimal. B2 is the most suitable zone for paddy and can produces high yields. Zone C2 and C3 are good for planting paddy once and secondary crops twice a year, but planting time need to be considered so it does not coincide with the dry month. D3 zone only allows to plant paddy and secondary crops once a year depending on the availability of water from irrigation or other sources. Zone E4 is a zone which is generally too dry so that it can only plant crops once a year.

Climate of Sangiran Site generally has 4 dry months and 6 wet months. According to the Oldeman, the criteria belongs to C2. Type C2 is adequate for three times crops. Palawija crops can be grow two times within a year, and paddy crops can only be grown once a year. Type C2 does not allow paddy crops due to the lack of wet periods. Furthermore, without a good irrigation system rainfed paddy crops are risky and prone to harvest failures.

4. Conclusion
Sangiran Site is a dry region due to the lack access to groundwater. Rainfed field makes up >5% of the landuse. The agriculture of the region is prone to harvest failures since Sangiran Site commonly experiences drought in dry season. Sangiran Site has monsoon pattern, with 6 wet months and 4 dry months. Rainfed field is at the highest risk when drought lasts for above four months. Farmers in Sangiran Site depend on rainfall to grow crops therefore they require to adapt to climate. According to the Oldeman classification, Sangiran Site has type C2. The farmers can adapt to C2 type to grow crops. The type C2 is adequate to plant crops three times a year, with two times palawija crops, and one time paddy. The Oldeman classification can be applied as a climate-based crop adaptation.

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