SIMULATION OF LANDCOVER CHANGE INFLUENCES FOR WATER AVAILABILITY USING A REGIONAL ATMOSPHERIC MODEL

E. Aldrian

Peneliti Madya Meteorology di UPT Hujan Buatan, BPP Teknologi
email: edvin@webmail.bppt.go.id

Abstract

A study of the landcover change impact on water budget has been done using a mesoscale climate model. A pristine lake catchment of Lake Poso in Central Sulawesi Province has been used for this study. A scenario for deforestation that change forest into savannah was performed for the dry period from July to December 2005 to simulate the severest possible scenario. The results show increase risks of flood during wet season and risks of drought during the dry season with highest increase of surface runoff up to 18% and decrease up to 10%. Meanwhile, the underground runoff increase during wet season up to 17% and decrease up to 10% during the dry season. This study may suitable for the climate change impact study and to simulate the land degradation due to ever increasing deforestation and land clearing.

Keyword: land surface modeling, MM5, water budget, regional climate model

1. INTRODUCTION

The rate of deforestation in Indonesia is among the largest in the world. Deforestation has been long blamed for water scarcity during the dry period, landslide and flood during the wet period. However, there is no study that directly link between impacts of deforestation to the water availability. Beside deforestation, other human activities that change landcover such as land clearing for agriculture, plantation and rural expansion has also been blamed for the natural destruction that leads into changes of water availability.

Recently the advance of mesoscale climate modeling has provide us with a tool for studying the impact of landcover change to water availability. Climate model simulation has advantage of simulating the natural destruction without really destructing the nature. In doing so, we will able to find answer of natural destruction by changing the landcover to water availability. The mesoscale climate model (MM5) is a non hydrostatic model based on linux OS that is very popular in the world and has been used by many national meteorological agencies in several countries. Although the new development has directed toward the new derivative of it called WRF, the popularity of MM5 remains unchallenged and still one of the mostly use for the local and regional scale. The current version of MM5 uses the NOAH land-surface model (Chen and Dudhia 2001a, 2001b). MM5 mesoscale climate model has been used in Indonesia for several study for example: Roswintiarti and Raman, 2003 and Gunawan 2006.

In this study we utilized a prestine condition where the least undestructed area could be used for the study. For an extreme natural condition, the deforestation was simulated using landcover conversion from forest into savannah. As the area for this study, the lake Poso catchment area has been chosen to represent the prestine area since this area is still undestructed from the landcover map. For example other areas such as Java, Sumatra or Kalimantan may not well suitable for such a study since most land degradation has already occurred.
Eventhough, similar study could be conducted for other areas as well. This study is then, illustrate a development of modeling scenatio and programming techniques for supporting the simulation. At the end, the water availability as represented by runoff at surface and underground will be assessed and compared between the result of pristine and destructed conditions.

2. DATA DAN METODA

2.1. The MM5 mesoscale atmospheric climate model

The input data used for the model simulation consists of landscape data such as the topography, landcover, soil type etc, also climate data from reanalyses by NCEP from USA known as FNL data. The reanalyses data was a product of the surface data from World Meteorological Organization (WMO) and atmospheric data from several observation around the world including satellite imagery, radio sonde and remote sensing data, which is then reconstructed with a GCM (Global circulation model) to be a package of reanalysis data with temporal resolution of 6 hour and the spatial resolution 110 km.

The following are the landscape data used for simulate the climate using MM5 for 1 km (30 second) resolution:

- VEG-USGS.30s → vegetation type
- SOILCATB.30s → soil type
- LWMASK-USGS.30s → land water masking
- E100N40.DEM → orography

Those data are available in the following internet site
- Global FNL data (2005-2006) http://www.mmm.ucar.edu/mm5/mm5v3/data/where_to_find_analyses.html
- Topography USGS, Landcover, Vegetation and Soil ftp://ftp.ucar.edu/mesouser/MM5V3/TERRAIN_DATA

2.2 The dimension and domain of Poso area for the regional climate model

Mesoscale model works with a nesting mechanism from the coarse resolution to the finer one since the FNL data at 110km resolution is too coarse for direct nesting into 1.6 km. A special convention of using MM5 grid resolution is that the coarser one shall be three times coarser resolution than the inner one. Hence, we use three step of nesting using resolutions 15, 5 and 1.6km.

We define then three main domains for our simulations as follow

- Domain 1, resolution of 15 km. the domain covers the North Sulawesi, central Sulawesi provinces and part of Southeast Sulawesi provinces and part of South Sulawesi, while the eastern part cover the central Sulawesi up to the Halmahera islands (1.55N-3S, 119E-130E).
- Domain 2, resolution of 5 km, covers the central part of the central Sulawesi province (0.8S-2.4S, 119.5E-121.8E).
- Domain 3, resolution of 1.6 km, covers only or focuses to the Poso district area with the lake Poso in the centre (1.25S-2.25S, 120.2E – 121.3E).
For this study we use the reanalyses (FNL) from NCEP that cover the second half of 2005. Data before this period is not prepared for the hydrometeorology analyses, only for meteorology since there is no soil temperature and moisture data (Dudhia, 1996). The MM5 model is prepared to run the simulation of hydrometeorology of domain 1, 2, 3 for the second half of 2005 with output every 6 hours. Thus we have results output at 00.00 – 06.00, 06.00-12.00, 12.00-18.00, 18.00-24.00 WITA.
In this study, we will observe the surface runoff (SRO), the total precipitable water (PW) or total rainfall and also underground runoff (URO). In the process, the data will be processed through a GrADS (The Grid Analysis and Display System) software based on linux OS. Figure 3.2 illustrates examples of topography output from each domain using GrADS software.

2.3 Modification of landcover as the scenario for environmental degradation

One of the inputs for climate simulation of MM5 is the land cover (VEG USGS), this data supply the landcover distribution with the classification on Table 1.

| Vegetation Integer Identification | Vegetation Description       | Albedo (%) | Moisture Avail. (%) | Emissivity (% at 9 mm) | Roughness length (cm) | Thermal Inertia (cal cm² k⁻¹ s⁻⁰·⁵) |
|----------------------------------|-----------------------------|------------|---------------------|------------------------|-----------------------|-----------------------------------|
|                                  |                             | Sum | Win | Sum | Win | Sum | Win | Sum | Win | Sum | Win | Sum | Win | Sum | Win | Sum | Win |
| 1 Urban                          |                             | 18  | 18  | 10  | 10  | 88  | 88  | 50  | 50  | 0.03 | 0.03 |
| 2 Dryln Crop. Past.             |                             | 17  | 23  | 30  | 60  | 92  | 92  | 15  | 15  | 0.04 | 0.04 |
| 3 Irrg. Crop. Past.             |                             | 18  | 23  | 50  | 50  | 92  | 92  | 15  | 15  | 0.04 | 0.04 |
| 4 Mix. Dry / Irrg. C.P.         |                             | 18  | 23  | 25  | 50  | 92  | 92  | 15  | 15  | 0.04 | 0.04 |
| 5 Crop. / Grs. Mosaic           |                             | 18  | 23  | 25  | 40  | 92  | 92  | 14  | 5   | 0.04 | 0.04 |
| 6 Crop. / Wood Mosaic           |                             | 16  | 20  | 35  | 60  | 93  | 93  | 20  | 20  | 0.04 | 0.04 |
| 7 Grassland                     |                             | 19  | 23  | 15  | 30  | 92  | 92  | 0.12 | 0.11 | 0.03 | 0.04 |
| 8 Shrubland                     |                             | 22  | 25  | 10  | 20  | 88  | 88  | 10  | 10  | 0.03 | 0.04 |
| 9 Mix Shrb. / Grs.              |                             | 20  | 24  | 15  | 25  | 90  | 90  | 11  | 10  | 0.03 | 0.04 |
| 10 Savanna                      |                             | 20  | 20  | 15  | 15  | 92  | 92  | 15  | 15  | 0.03 | 0.03 |
| 11 Decids. Broadlf.             |                             | 16  | 17  | 30  | 60  | 93  | 93  | 50  | 50  | 0.04 | 0.04 |
| 12 Decids. Needlf.              |                             | 14  | 15  | 30  | 60  | 94  | 94  | 50  | 50  | 0.05 | 0.05 |
| 13 Evergn. Broadlf.             |                             | 12  | 12  | 50  | 50  | 95  | 95  | 50  | 50  | 0.04 | 0.05 |
| 14 Evergn. Needlf.              |                             | 12  | 12  | 30  | 60  | 95  | 95  | 50  | 50  | 0.04 | 0.06 |
| 15 Mixed Forest                 |                             | 13  | 14  | 30  | 60  | 94  | 94  | 50  | 50  | 0.04 | 0.06 |
| 16 Water Bodies                 |                             | 8   | 8   | 100 | 100 | 98  | 98  | 0.01 | 0.01 | 0.06 | 0.06 |
| 17 Herb. Wetland                |                             | 14  | 14  | 60  | 75  | 95  | 95  | 20  | 20  | 0.06 | 0.06 |
| 18 Wooded Wetland               |                             | 14  | 14  | 35  | 70  | 95  | 95  | 40  | 40  | 0.05 | 0.06 |
| 19 Bar. Sparse Veg.             |                             | 25  | 25  | 2   | 50  | 85  | 85  | 10  | 10  | 0.02 | 0.02 |
| 20 Herb. Tundra                 |                             | 15  | 60  | 50  | 90  | 92  | 92  | 10  | 10  | 0.05 | 0.05 |
| 21 Wooded Tundra                |                             | 15  | 50  | 50  | 90  | 93  | 93  | 30  | 30  | 0.05 | 0.05 |
| 22 Mixed Tundra                 |                             | 15  | 55  | 50  | 90  | 92  | 92  | 15  | 15  | 0.05 | 0.05 |
| 23 Bare Gmd. Tundra             |                             | 25  | 70  | 2   | 95  | 85  | 85  | 0.1 | 5   | 0.02 | 0.05 |
| 24 Snow or Ice                  |                             | 55  | 70  | 95  | 95  | 95  | 95  | 5   | 5   | 0.05 | 0.05 |

In this study, we will modify the land cover from VEG-USGE with a scenario of total deforestation (most severe degradation) that could occur over the Poso catchment, where the forests (11-15) are converted into savannah (10). Similar scenario has been done for amazon (Marengo, 2006). This is done by changing the pixel values around the lake Poso that has values between 11 and 15 into 10. This process was done under special programs (provided in annexes part of this study) that converts binary into ASCII of VEG-USGS and then manipulated in the regular spread sheet program like Excel. As the consequence of changing the land cover is changes in surface properties such as the runoff coefficient as the most important one for this study. The runoff coefficient determines portions of water that goes in surface or underground runoff. The USGS runoff coefficient as also used in MM5 simulation is given in Table 2.
Table 2 USGS method of calculating runoff coefficient
(source: http://igs.indiana.edu/survey/projects/hydrotools/html_files/element2.cfm)

| USGS LU Id | USGS LU Description | IGS LU Description | IGS LU Id | Run-Off Coefficient |
|------------|---------------------|--------------------|-----------|---------------------|
| 3          | Irrg. Crop. Past.   | Crops              | 7         | 0.4                 |
| 4          | Mix. Dry / Irrg. C.P.| Crops              | 7         | 0.4                 |
| 5          | Crop. / Grs. Mosaic | Crops              | 7         | 0.4                 |
| 6          | Crop. / Wood Mosaic | Crops              | 7         | 0.4                 |
| 7          | Grassland           | Grasslands/herbaceous/shrublands | 6 | 0.25               |
| 8          | Shrubland           | Grasslands/herbaceous/shrublands | 6 | 0.25               |
| 9          | Mix Shrb. / Grs.    | Grasslands/herbaceous/shrublands | 6 | 0.25               |
| 10         | Savanna             | Grasslands/herbaceous/shrublands | 6 | **0.25**           |
| 11         | Decids. Broadlf.    | Forest             | 5         | 0.15                |
| 12         | Decids. Needlf.     | Forest             | 5         | 0.15                |
| 13         | Evergrn. Broadlf.   | Forest             | 5         | 0.15                |
| 14         | Evergrn. Needlf.    | Forest             | 5         | 0.15                |
| 15         | Mixed Forest        | Forest             | 5         | 0.15                |
| 16         | Water Bodies        | Water              | 0         | 0                   |

The grid that we converted is within the 46x66 dimension around the Poso lake, with the coordinate between 2.25S – 1.72S and 120.4E – 120.78E as shown in Fig. 3.

Figure 3 Landcover map of Poso district before (left) and after (right) modification
3. RESULTS

3.1. Climatology of study area

The following table shows the climatology of the Poso area based on available data of rainfall observation mainly from 1984 to 1990. After that period only data from Kasiguncu (Poso city airport) is available until present. Beside that table, Fig. 5 shows the average of rainfall during that period with the total area average in bold. The above average rainfall represents stations in high altitude or upstream near the Poso lake, while the below average curves represents data near shoreline or downstream areas. The climatology indicates that July to December represents the peak of the dry season, which is the most crucial time of the year for water availability.

Table 3 Average monthly rainfall (1984-1990)

| Station     | lat  | lon  | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-------------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Pandayora   | S 2°11' E 120°42' | 222  | 327 | 335 | 396 | 392 | 302 | 269 | 90  | 159 | 174 | 253 | 326 |
| Kamba       | S 1°54' E 120°55' | 153  | 117 | 228 | 241 | 125 | 128 | 89  | 58  | 90  | 37  | 128 | 194 |
| Kolonodale  | S 1°39' E 121°2'8 | 106  | 96  | 196 | 212 | 264 | 238 | 313 | 330 | 102 | 154 | 123 | 196 |
| Mayoa       | S 2°13' E 120°45' | 378  | 323 | 464 | 483 | 443 | 261 | 182 | 242 | 265 | 338 | 275 |
| Tentena     | S 1°45'' E 120°39' | 132  | 78  | 194 | 312 | 264 | 166 | 112 | 63  | 105 | 164 | 188 | 291 |
| Wuasa       | S 1°25'' E 120°26' | 73   | 92  | 146 | 157 | 116 | 55  | 86  | 65  | 90  | 95  | 151 | 147 |
| Pendolo     | S 2°7' E 120°43' | 377  | 276 | 492 | 400 | 373 | 305 | 249 | 155 | 113 | 142 | 256 | 374 |
| Kasiguncu   | S 1°23' E 120°44' | 216  | 183 | 234 | 277 | 275 | 181 | 192 | 148 | 124 | 198 | 228 | 184 |
| avg         |      |      | 207 | 187 | 286 | 310 | 282 | 205 | 196 | 136 | 128 | 154 | 208 | 248 |

Figure 5 Climatology of rainfalls over the Poso area between 1984-1990.
3.2. **The calculation of the area average**

The FNL data from NCEP has the runoff (SRO) from July to December 2005, and has been simulated for about 6 months until December 2005 for comparison with the output of total rainfall or precipitable water (PW) and runoff (SRO) between the scenario of landcover or land cover and the original actual landcover from VEG-USGS over the Poso catchment are, then we call the original landcover as the control run. The process of data was done for Domain 3 only at the resolution 1.6 km and covers the whole lake Poso catchment.

To quantify the output of model we have done the area average of the Poso catchment area. This process was done firstly by a masking process that limits the data only within the Poso catchment. The masking process in principle is to filter model output with desired area by multiplying the output PW and SRO with the data package of 1 for the Poso catchment and 0 for the other. This process is done with the GrADS software. After masking, we could calculate the area average of the rainfall and runoff from the catchment.

![Figure 6](image6.png)  
**Figure 6** An example of overlay from the rainfall spatial map (left) and the runoff map (right) with their respective masking layer.

For the rainfall, we are using the whole catchment of Lake Poso, while for the runoff was done only the catchment area minus the lake area, since there is no runoff from the lake but into the lake. The finished masking process is given in Figure 7 that only display data over the area that we wanted only. In this case the lake Poso. After the masking, the area average of the catchment could be done for the whole simulation period.

![Figure 7](image7.png)  
**Figure 7** Example of multiplication of spatial rainfall (left) and run-off (right) with associated masking.
3.3. **The comparison of area average between two scenarios**

After simulation of about six months from July to December 2005, the area average of the Poso Lake with the masking. Both data series will be compared to see the percentage of change. The output from the precipitable water (PW) or rainfall, surface runoff (SRO) and underground run-off (URO) differences from both scenarios can be seen from Figure 8. The percentage from that figure is the differences between the changes of SRO and PW to the control output. Then for the average of percentage is the comparison between average differences of SRO and PW of scenario to control run.

The positive percentage indicates the increase, while the negative percentage indicates a reduction from the scenario against the control output. In average the increase of run off from the land cover change from forest into savannah for the first 3 months is about 12.99% and for the rainfall will increase about 7.17%. While for the latter 3 months of simulation when the peak of the dry season, there are decrease for all three parameters.

Figure 8 The first three months of simulation (July – September 2005) of Precipitable water/Rainfall (PW), Surface Runoff (SRO) and Underground Runoff (URO) inside the catchment of lake Poso
Salim (2007) indicates from his modeling of deforestation of Borneo that during the rainy season deforestation will increase the local sensible heat flux that increase the evaporation and hence convective rainfall. Increase of rainfall will then increase surface runoff. The reverse condition occurs during the dry season, when lacks of rainfall will take away the runoff.

4. CONCLUSIONS
A study of impacts of land degradation and its impact to water availability has been done for the Poso catchment area. A special programming technique and model treatment has been used to simulate the natural degradation by changing the forest cover into savannah. From the above percentage the replacement of the land cover from forest into savannah will increase the run off and precipitation in the wet season and reduce them during the dry season. We notice that the increase is decreasing when we enter the dry season. On the other hand the decrease is also decreasing when we enter the end of dry season. Results of this simulation imply that the deforestation will increase the risk of flood (high surface runoff) during wet period and increase the risk of drought during the dry season.

References
Chen, F. and J. Dudhia, 2001a: Coupling an advanced land-surface/hydrology model with the Penn State/NCAR MM5 modeling system. Part I: Model implementation and sensitivity. Mon. Wea. Rev., 129, 569-585.

Chen, F. and J. Dudhia, 2001b: Coupling an advanced land-surface/hydrology model with the Penn State/NCAR MM5 modeling system. Part II: Preliminary model validation. Mon. Wea. Rev., 129, 587-604.

Dudhia J, 1996: A multi-layer soil temperature model for MM5, Preprint from the Sixth PSU/NCAR Mesoscale Model Users' Workshop.

Gunawan D. 2006, Atmospheric Variability in Sulawesi, Indonesia - Regional Atmospheric Model Results and Observations, Dissertation, Georg-August-Universität Göttingen

Marengo, JA, 2006, Amazon Forest Will Turn into a Savannah in Less than 100 years - Due to global warming, http://news.softpedia.com/news/Amazon-Forest-Will-Turn-into-a-Savannah-in-Less-than-100-years-43382.shtml
ROSWINTIARTI O and S. Raman, 2003, Three-dimensional Simulations of the Mean Air Transport During the 1997 Forest Fires in Kalimantan, Indonesia Using a Mesoscale Numerical Model, Pure Appl. Geophys. 160, 429–438

Salim SA, 2007, Analisis dampak perubahan tutupan lahan hutan terhadap 4 unsur iklim di Kalimantan menggunakan model iklim regional REMO, skripsi sarjana IPB, Department of Agrometeorology IPB, 30 pp
Annex 1. A program to read USGS Land cover data and convert into text file (Excell ready)

```c
main() {
    #include <stdio.h>
    #include <stdlib.h>
    #include <string.h>

    #define NCOLS  43200 /* Number of Longitudes - */
    #define NROWS  21600 /* Number of Latitudes - */
    #define NORTH  -1 /* Poso north border */
    #define SOUTH  -3 /* Poso south border */
    #define WEST   120 /* Poso west border */
    #define EAST   121 /* Poso east border */

    FILE *finp, *fout; /* input output files */
    unsigned char cline[NCOLS];
    int iline, il,lonc,latc;
    float fch;

    lonc=21600;
    latc=10800;

    finp = fopen("VEG-USGS.30s","rb");
    fout = fopen("poso-usgs.txt","w");
    for (iline=0; iline<NROWS; iline++){
        fread(cline,sizeof(char),NCOLS,finp);
        if ((iline>= latc-120*NORTH) && (iline< latc-120*SOUTH)){
            for (il=120*WEST+lonc; il<120*EAST+lonc; il++){
                fprintf(fout, "%d ",cline[il]);
            }
            fprintf(fout, "\n");
        }
    }
    fclose(finp);
    fclose(fout);
}
```

Annex 2. A program to read text file (Excell ready) and convert into USGS Land cover data

```c
main() {
    #include <stdio.h>
    #include <stdlib.h>
    #include <string.h>

    #define NCOLS  43200 /* Number of Longitudes - */
    #define NROWS  21600 /* Number of Latitudes - */
    #define NORTH  -1 /* Poso north border */
    #define SOUTH  -3 /* Poso south border */
    #define WEST   120 /* Poso west border */
    #define EAST   121 /* Poso east border */

    FILE *finp, *finp2, *fout;
    unsigned char cline[NCOLS];
    int iline, il;
    int nl,ns,lonc,latc,cpos[240][120];

    lonc=21600;
    latc=10800;

    finp = fopen("VEG-USGS.30s","rb");
    finp2 = fopen("poso-usgs-p.txt","rb");
    fout = fopen("VEG-USGS.30s-m","w");
```
for (nl=0; nl<240; nl++){
    for (ns=0; ns<120; ns++){
        fscanf(finp2, "%2d  ", &cpos[nl][ns]);
    }
    fscanf(finp2, "\n");
}
for (iline=0; iline<NROWS; iline++){
    fread(cline, sizeof(char), NCOLS, finp);
    /* first north, then south border */
    if ((iline>= latc-120*NORTH) && (iline< latc-120*SOUTH)){
        printf("line %d; cpos %d\n", iline, iline-(latc-120*NORTH));
        for (il=120*WEST+lonc; il<120*EAST+lonc; il++){
            cline[il]=(char)cpos[iline-(latc-120*NORTH)][il-120*WEST+lonc];
        }
    }
    fwrite(&cline, sizeof(char), NCOLS, fout);
}
fclose(finp);
fclose(finp2);
fclose(fout);