Analysis of land cover change and rainfall on the global land surface water coverage database for 1987-2015

X Li and W Takeuchi
Institute of Industrial Science, The University of Tokyo, Ce-506, 6-1, Komaba 4-chome, Meguro, Tokyo 153-8505, Japan
lixi@iis.u-tokyo.ac.jp

Abstract. In this paper, taking into account population density of the world, major river basin was delineated continent wise all over the world using HYDRO1k data. Then, monthly rainfall change from the year 1981 to 2014 and daily LSWC (Land surface water coverage) change from 1987 to 2015 based on each major river basin was computed and compared with each other. A good agreement was found between LSWC pattern and rainfall pattern, showing a seasonal variation characteristic in each year. However, it could be seen that rainfall is not the only factor that bring about change in LSWC. Also, it was found that the change of urban area is very strong. Especially in Yangtze basin, from 2000 to 2012, the urban changed from 0.07% to 0.83%. Moreover, the proportion of cropland increased significantly, especially in Ganges basin increased by 57.64%, grew to nearly 70% from 1992 to 2012. Besides, the trend of consistent growth was showed both in cropland and LSWC. It is indicated that the widespread expansion of cropland may bring about LSWC increasing.

1. Introduction
Flooding is known as frequent and most devastating event worldwide. Flooding analysis and estimate has received great attention of planners and decision makers in government and enterprises in order to master accurate information and mitigate catastrophic effects [1]. Since flood events are dynamic processes, high temporal resolution data is a desirable condition for flooding studies [2]. In previous research, global daily LSWC database derived from passive microwave radiometers including SSM/I, AMSR-E, WindSAT, AMSR2 during 1978-2015 has been made. and indicated its availability and potential in flood events detection [3-5] since LSWC could be associated to relative increase of both water and soil moisture [6].

Land cover change is known to influence both surface water hydrology and soil hydraulic properties by altering the hydrological characteristics of the land surface and modifying the patterns and rates of water flow [7]. In addition, rainfall also seriously influences open water and soil moisture and thus plays an important role in flooding researches. Ohana-Levi has modeled the effects of land cover change on rainfall runoff relationships in a Semiarid, Eastern Mediterranean watershed, which was found a strong relationship between vegetation cover and the runoff volume. Moreover, the land cover changes with most pronounced effects on runoff volumes were related to urbanization and vegetation removal [8]. Panahi discussed the effect of land use/cover changes on the floods of the Madarsu basin of northeastern Iran which was found that the discharge rate of 2003 flood was about 10 times larger than that of the 1964 flood, since the direct effect of the land use/cover change from
the stable forests and rangelands to the unstable agricultural lands on the both soil moisture retention capacity and run off rate [9]. Ferrazzoli carried out analysis of the effect of rain and flooding events on AMSR-E Signatures of La Plata Basin, Argentina, which has been found that the amount of the effect and the correlation between variables are dependent on the properties of the areas surrounding the stations [10]. Hydrological response to land cover change and human activities in arid regions using a geographic information system and remote sensing has been discussed by Mahmoud which has been indicated that changes in land cover are predicted to result in an annual increase in irrigated cropland and dramatic decline in forest area in the study area over the next few decades [11].

However, most of this field of research is aimed at a certain watershed or a region until now. Therefore, the objective of this study is to make clear rainfall pattern of each major river basin worldwide and analysis the effects of land cover change and rainfall on the global LSWC database during 1987-2015 derived from passive microwave remote sensing.

2. Methodology

2.1. The flowchart of this study

Figure 1 shows the framework of this research. Firstly, taking into account population density of the world, global major river basins were derived from HYDRO1k data. Secondly, combining with major river basins, CRU_TS precipitation dataset from 1981 to 2014 was integrated to obtain the rainfall pattern of each river basin in order to compare with LSWC pattern of each river basin. Thirdly, from land cover map of 1992 (UMD LC), 2000 (GLC2000) and 2012 (BU LC), cropland, forest, urban and water body were masked out respectively and the percent area change of each land cover type in each river basin was calculated to explore its relationship with LSWC change.

![Figure 1. The flowchart of this study.](image)

2.2. River basin delineation using HYDRO1k

HYDRO1k is a geographic database developed to provide comprehensive and consistent global coverage of topographically derived data sets, which provides a standard suite of geo-referenced data sets at a resolution of 1 km. The HYDRO1k data sets are being developed on a continent-by-continent basis, for all landmasses of the globe without Antarctica and Greenland.

Vector river basin data from HYDRO1k was imported into ArcGIS 10.2.2 for processing. After converting the projection from Lambert-Azimuthal Equal Area to Geographic Lat/Lon in WGS84, the first level of basins were highlighted and selected based on the Pfafstetter Coding System [12]. Thereafter by combining it with population density data of the world, derived from gridded population of the world (GPW) which provides estimates of population density for the years 2000, 2005, 2010, 2015 based on counts consistent with national censuses and population registers with respect to
relative spatial distribution [13-14], a subdivision for the first level of river basin were carried out in densely populated or river rich areas.

2.3. Rainfall pattern analysis by CRU_TS_v3.23
The gridded CRU_TS (time-series) v3.23 dataset, produced by the Climatic Research Unit (CRU) at the University of East Anglia, provides month-by-month variations in climate over the period from 1901 to 2014 with 0.5×0.5 degree grids [15-16]. Firstly the same coordinate system (Geographic Lat/Lon in WGS84) was defined to CRU_TS precipitation data as projection of river basin in order to combine rainfall dataset with river basin. Then rainfall pattern of each major river basin was computed by integrating long time series of data from 1980 to 2014 in order to compare with the LSWC pattern of the same river basin.

2.4. Land cover change analysis
The land cover maps from year of 1992 (UMD_LC), 2000 (GLC2000) and 2012 (BU_LC) were used to discuss and explore the relationship between land cover change and LSWC change [17-19]. The specification of three land cover products is shown in Table 1 [20-20]. Based on three kind of classification schemes and conversion legends as shown in Table 2 [22], urban area, forest, cropland area and water body for the years 1992, 2000 and 2012 was masked out respectively. Finally the land area change of each land cover type in each major river basin was calculated.

| Global land cover data set | Classification scheme | Sensor | Date  | Number of classes | Resolution |
|----------------------------|-----------------------|--------|-------|-------------------|------------|
| UMD_LC                    | Simplified IGBP       | AVHRR  | 1992  | 14                | 1km        |
| GLC2000                   | FAO LCCS              | SPOT-4 | 2000  | 23                | 1km        |
| BU_LC                     | IGBP                  | MODIS  | 2012  | 17                | 1km        |

**Table 2.** Conversion legends table of three land cover maps.

| Target legend | 1992 (UMD-LC) | 2000 (GLC2000) | 2012 (BU-LC) |
|---------------|--------------|----------------|-------------|
| Cropland      | Class 11     | Class16-18     | Class 12, 14|
| Forest        | Class1-6     | Class1-6, 9-10 | Class 1-5, 8|
| Urban         | Class 13     | Class 22       | Class 13    |
| Water         | Class 0      | Class 20       | Class 0     |

3. Results and discussion

3.1. River basin delineation using HYDRO1k
Global map of gridded population density in 2015 was prepared and the first level river basins all over the world were derived from HYDRO1k data set. Figure 2 shows the gridded population density of the world in 2015 overlaid by the first level of river basins wherein each pixel value represents persons per square kilometer. It can be seen that the population density in Asia and some area in Europe and Africa is very high, especially that in India, Bangladesh and China is much high.
Since flooding causes more damage in densely populated areas. Therefore, taking into account the river distribution and population density we carried out a subdivision for the first level river basin in densely populated or rich basin area and finally got the global major river basins with ID as shown in Figure 3. Table 2 shows the list of several significant major river basins and the corresponding ID of each continent.

Table 3. Selected several major river basins and the corresponding ID by continents.

| Continent | ID  | River basin          | ID  | River basin          |
|-----------|-----|----------------------|-----|----------------------|
| North America | 120  | Mackenzie            | 160  | St Lawrence          |
|           | 140  | Saskatchewan/Nelson  | 180  | Mississippi          |
| South America | 240  | Amazon Basin        | 280  | La Plata Basin       |
| Africa    | 320  | Nile                 | 360  | Congo                |
|           | 340  | Zambezi              | 380  | Niger                |
| Europe    | 420  | Tigris/Euphrates    | 480  | Danube               |
| Asian     | 510  | Brahmaputra Basin    | 580  | Amur Basin           |
|           | 511  | Ganges               | 591  | Huang He Basin       |
|           | 515  | Indus Basin          | 592  | Yangtze Basin        |
|           | 520  | Ob                   | 594  | Mekong Basin         |
|           | 540  | Yenisey              | 596  | Irrawaddy Basin      |
3.2. Comparison between rainfall pattern and LSWC pattern

In order to make clear the relationship between rainfall and LSWC, the monthly precipitation change of all river basins worldwide was computed by integrating long-term monthly CRU precipitation dataset from 1981 to 2014. Three major river basins, which are Brahmaputra (510), Ganges (511) and Yangtze (592), from Asian were chosen for further analysis. In addition, in previous research, we built long-term LSWC database in time series from 1987 to 2015 by combining SSM/I, AMSR-E, WindSat and AMSR2 [3-5]. LSWC has been proved a good performance in large-scale flooding detection. Then, daily LSWC change from 1987 to 2015 based on each river basin was also computed.

Figure 4 shows the corresponding relationship between precipitation and LSWC. It can be seen that the LSWC pattern basically coincides with the rainfall pattern, showing a seasonal variation characteristic within each year. Moreover in the long term, the trend of continued growth or decreasing in rainfall is not clear whereas LSWC showed an increasing trend according to the trend line through 1987 to 2015. Compared to previous years, increase in average LSWC value after 2000 was 2% for Brahmaputra, 1% for Ganges and 1% for Yangtze than before 2000. It can be indicated that rainfall is not the only factor that makes the change of LSWC.

3.3. Land cover change analysis

To further explore factors affecting LSWC, land cover change has been discussed. Figure 5 shows the change in cropland, forest, urban and water body area among the years 1992, 2000 and 2012 for the Brahmaputra (510), Ganges (511) and Yangtze basin (592). We saw that the proportion of forest area showed a decreasing trend and no much change observed for the Yangtze basin. Moreover a strong increase in urban area was also found in each basin. Especially in Yangtze basin, from 2000 to 2012, the urban region increased from 0.07% to 0.83%. It can also be seen that from 1992 to 2000 and then
to 2012, the proportion of croplands increased significantly. Brahmaputra basin area increased by 13.78%, Yangtze basin increased by 22.01%, especially Ganges basin increased by 57.64%, grew to nearly 70%.

By comparing cropland with LSWC change from 1992, 2000 to 2012 in each basin as shown in Table 4, we can find that the cropland presented consistent growth situation along with LSWC. According to the relative change in Brahmaputra basin, the croplands increased by 8% and 6%, while LSWC increased by 4% and 3%. It is hypothesized that since during sowing season irrigation causes cropland surfaces to be covered by water, it could have led it to be detected as an inundated area. Moreover, since the increase of human population and standards of living demand more harvest and production from the earth resources, increased irrigation frequency or sowing time in one year can be anticipated. Thus it is expected that the widespread expansion of cropland may bring about LSWC increasing. In addition, it can also be inferred that the rapid expansion of urban and reduction of forest area may be factors affecting LSWC change.

![Figure 5](image)

**Figure 5.** Land area change of different land cover type for 1992, 2000 and 2012 in three river basins.

**Table 4.** Compare of cropland and LSWC change from 1992, 2000 to 2012 in three basins.

| River basin | Category | Percentage (%) | Relative change | 1992-2000 | 2000-2012 |
|-------------|----------|----------------|-----------------|-----------|-----------|
| Brahmaputra | Cropland  | 6  14  20  8  6 |                |           |           |
|             | LSWC     | 7  11  14  4  3 |                |           |           |
| Ganges      | Cropland  | 12  45  70  33 25 |                |           |           |
|             | LSWC     | 4  5   6   1   1 |                |           |           |
| Yangtze     | Cropland  | 12  21  34  9  13 |                |           |           |
|             | LSWC     | 4  6   8   2   2 |                |           |           |

4. Conclusion and future work
In this paper, firstly, taking into account population density of the world we delineated major river basin continent wise all over the world using Hydro 1k data. Secondly, by comparing precipitation monthly change with LSWC daily change of each river basin, we found that LSWC pattern basically coincide with rainfall pattern, showing a seasonal variation characteristic in each year. However rainfall is not the only factor that brings about the change in LSWC. Finally, it was found that the change in urban was very strong in Yangtze basin, from 2000 to 2012, changed from 0.07% to 0.83%. Moreover, the proportion of cropland increased significantly, especially Ganges basin increased by 57.64%, grew to nearly 70%. In addition the trend of consistent growth was showed both by cropland and LSWC. It is expected that the widespread expansion of cropland may bring about LSWC increasing.
For the future work, we advance to analyse all the river basin worldwide in order to find regulation among rainfall, land cover change and LSWC. Moreover, we wish to conduct spatial analysis of land cover change and combine factors of social economy to explore its influence on LSWC change.

Nomenclature

| Abbreviation | Description |
|--------------|-------------|
| LSWC         | Land Surface Water Coverage |
| SSM/I        | Special Sensor Microwave Imager |
| AMSR-E       | Advanced Microwave Scanning Radiometer - Earth Observing System |
| AMSR2        | Advanced Microwave Radiometer - 2 |
| CRU_TS       | Climatic Research Unit - Time Series |
| UMD_LC       | University of Maryland - Land Cover product |
| GLD2000      | Global Land Cover 2000 |
| BU_LC        | Boston University – Land Cover product |
| IGBP         | International Geosphere Biosphere Programme |
| FAO LCCS     | Land Cover Classification System of Food and Agricultural Organizations |
| AVHRR        | Advanced Very High Resolution Radiometer |
| SPOT-4       | Satellite Pour l’Observation de la Terre - 4 |
| MODIS        | Moderate Resolution Imaging Spectroradiometer |

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