OBJECT–BASED IMAGE CLASSIFICATION AND WEB-MAPPING TECHNIQUES FOR FLOOD DAMAGE ASSESSMENT

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ABSTRACT

The importance and power of geospatial information technology was proven during the recent (June 2008) Midwest floods in some low lying areas along the river courses. This paper studies the use of the Landsat satellite images to assess the flood damages in nine of the counties in southern Indiana, and the development of Web-based mapping and reporting based on the Google Earth API technique.

The Landsat images acquired on June 11, 2008 became the most relevant data as the peak flooding was observed on June 10 and 11 in this area. The availability of June 12, 2007 Landsat imagery over the same area enables us to observe the changes and accurately map the flood extents. To do so, both temporal images were classified using object–based image classification method to avoid the inherent problems of the traditional pixel-based methods. In this technique, segmentation produces homogeneous regions or objects with spectral, spatial and texture features. This substantially improves the classification results. The results are then made available on the Internet through Google Earth API (Application Programming Interface) released by Google in June 2008. We embed a number of functionalities of visualization and query of Google Earth into our own webpage using GE API and script language. Its availability on the Web helps decision makers to respond and take necessary actions against such natural hazards.

Based on this study, it is found that most of the damages were caused to the standing crops at the early stage of their growth. Crops Data Layer 2007 (CDL) of USDA was used to assess the crops damage, assuming the similar crops in the same areas during year 2008. The results show that an average about 15-16% of corn and soybean, 5% of wheat and 5% of pasture and hay were affected by the flooding. Comparison with Indiana Department of Transportation (INDOT) roads 2005 data shows that about 5% of the roads (mostly county roads) were affected by the flooding.

Keywords: Temporal satellite images, Object–based classification, Change detection, Floods mapping, Damage assessment, Web mapping, Web-GIS

INTRODUCTION

The June 2008 floods in the southern Indiana caused heavy losses to the urban and agricultural areas. People were forced to abandon homes as mostly the areas along river courses were inundated to a dangerous level. These floods were a result of heavy week-long rainfall all over Indiana. The accumulated rainfall raised the river water to the record levels as documented by USGS operated gauging stations. In addition to rivers and streams, large areas away from these were subject to flood due to heavy surface runoff, which added more severity as predicted from the gauge data. Satellite remote sensing data can play a vital role for rapid mapping of the disaster extent and impact. The timely provision of such information and products directly to the disaster management agencies and on the Web can support forming quick response strategies and help in the rescue and relief effort tremendously.

A timely acquisition of Landsat data over the flood areas and availability of the temporal data of same time same area proved extremely valuable for assessment of preliminary flood damages at a large scale. The image classification results integrated with ancillary data did help to estimate damages to the major standing crops, roads and street and the analysis of designated floodplains. The mapping results of flood extent were immediately published on the Web through Google Earth API with data visualization and query capabilities, and was regularly updated with the additional analysis results such as flood change maps, crops and urban area damage estimates. The availability geospatial data on the Web help the authorities to visualize the spatial distribution and extent of this natural hazard spread over a large area and to take necessary remedial measures in the quickest way.

RAINFALL AND RIVER WATER LEVELS

During the first week of June, 2008 most parts of the Indiana received approximately 7-10 inches heavy rainfall, especially Clay, Owen and Greene counties in southern Indiana. It started early in the week and intermittently continued until the second week. The highest official rainfall of 9.50 inches was recorded on June 7th from 3 miles east of the Center Point in Clay County, Indiana. The average rainfall for this month was 8.00 inches, 3.87 inches above normal [1]**Error! Hyperlink reference not valid.** The precipitation map for the first week of June (1- 7 June) in Figure 1 shows the severity of this rainfall in southern Indiana.

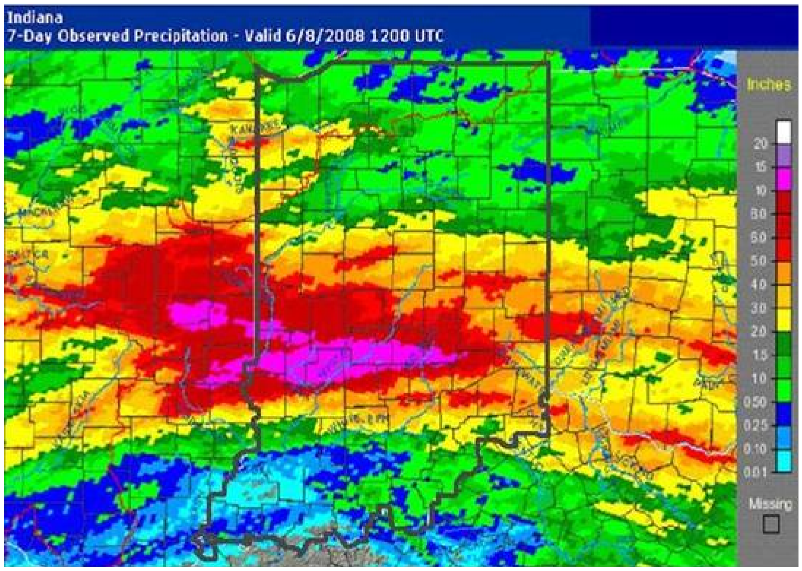


Figure 1. Precipitation map for the first week of June (1- 7) 2008 (courtesy National Weather Service).

These high rainfalls resulted into severe flooding in the rivers flowing through south central and southern Indiana and caused heavy destruction to both urban areas and agricultural land. River water levels exceeded the flood stage by almost doubles as recorded by the National Weather Service (NWS)/USGS operated gauging stations [2]. These water levels were much higher than many previous years. This data did help USGS to predict floods downstream but the flow of excessive rainfall over the plain areas did add more severity as predicted. The major rivers flowing through these areas are Wabash, White and East Fork White River and number of streams. The heavy flooding situation in these water channels remained for about 6 days (June 8 to June 13, 2008). The severity of this heavy flooding can be seen by comparison of the water levels recorded at various location for Wabash and White river for year 2007, 2008 and the flood stage levels, given below in Figure 2 and 3.

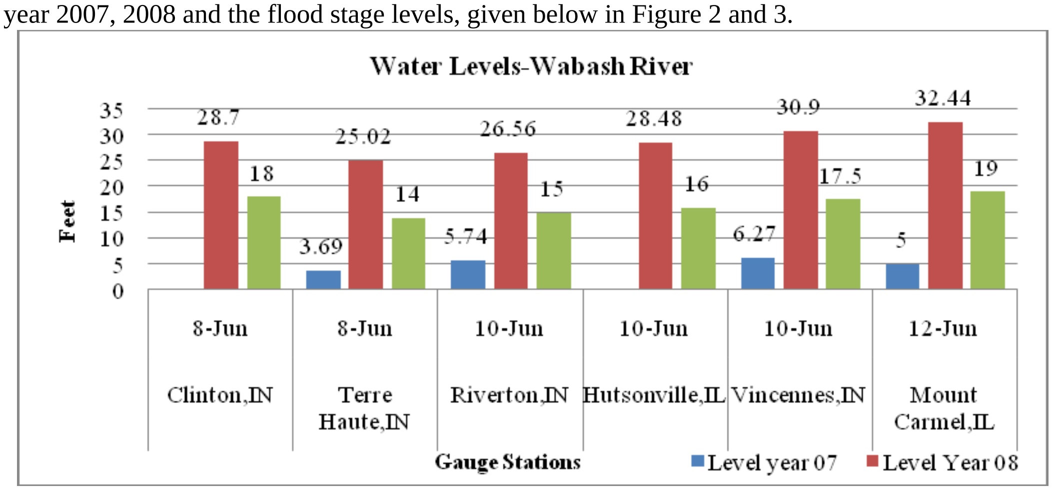


Figure 2. USGS water gauge station data for Wabash River.

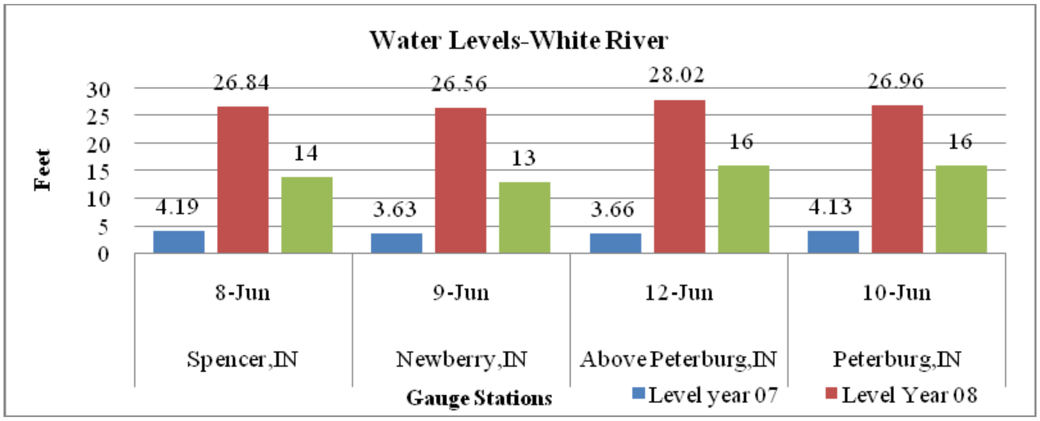


Figure 3. USGS water gauge station data for White River.

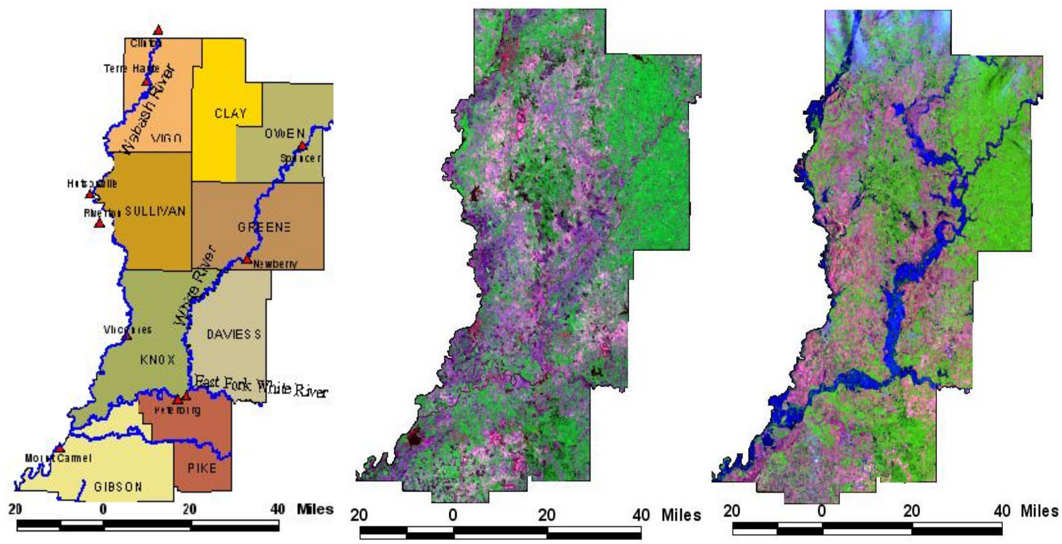
REMOTE SENSING DATA AND FLOOD MAPPING

Landsat Data

Satellite remote sensing data is one of the cost effective and accurate methods of mapping natural hazards spread over broad areas such as floods. Satellite data is more relevant for such mapping due to large area coverage, timely availability and temporal frequency. It can help the authorities in rescue efforts, damage assessment and future planning to take remedial measures and safe guard such event effectively. A range of satellite data sources are suitable for varying degrees of damage assessment, like Landsat, SPOT, IKONOS, QuickBird and OrbView. The selection of a particular data source depends mainly upon the timely coverage, its availability, spatial, spectral and temporal resolution and finally the costs.

June 11, 2008 was generally a clear sky day in the southern Indiana thus resulted into a better recording of the flood situation by Landsat-5 satellite imagery. This large area coverage remote sensing data provides an analysis threshold and information about the extent and damages caused by the flood. This Landsat image along with another Landsat image acquired on June, 9 2007, nearly the same time and same area, were made available on the 14th June courtesy of USGS through Envision Center Purdue University [3]. This data covers mostly the southern areas of Illinois and Indiana States. The availability of temporal dataset help greatly in analysis of the changes occurred due to the flooding. Pre flood event June 2007 imagery clearly shows the normal situation of water bodies like rivers, streams and other lakes and ponds in this area. It also helps to visualize the extent of the flood plains all along the river courses.

The latest Landsat image of June 11, 2008 is the best data for the assessment of the extent of this flood as the peak flooding in these areas was observed on June 10th and 11th. As by this time the water from northern parts and the adjoining areas subsequently surged along central and western areas leading to the southern areas. The real time data reported by NWS [1] and the readings from established gauge stations show that Wabash and White Rivers [2] to have seen heavy surges, along with the other small rivers and streams. Visual observation of the imagery revealed that nine counties were the most affected in southern Indiana, and thus these were selected as the study area. The study area with gauge station locations and rivers and the available Landsat image data is shown below in Figure 4.



(a) (b) (c)

Figure 4. Study areas county map with gauge stations (a), Landsat images for 2007(b) and 2008 (c).

Image Classification

For the analysis and assessment of the flood extent and damages to the agricultural produce both temporal images were classified using object based method. This method uses fuzzy rules based techniques to classify image objects rather than individual pixels. Object-based image analysis is often carried out in two steps, i.e. image segmentation and object classification. The first step, image segmentation is the division of an image into spatially continuous, disjoint and homogeneous regions. It is the prerequisite for object-based classification, in which an object or segment other than a pixel is used for classification. The aim of segmentation is to create meaningful objects by using appropriate methods and scale, shape and color parameters to maintain the geometry of the objects as closely as possible [4]. With the careful selection of segmentation parameters, object primitives with near original geometry can be achieved. At the second step, these objects are classified using object's spectral, contextual and textural features. A proper selection of features with well defined fuzzy membership functions for every class would allow for a better classification and produces very homogenous thematic map. The classification results depend on these input features and the degree of membership value of a class. The closer the membership value to 1 with no or less alternative assignments, the more stable the classification results.

For this study both the images were classified into five major classes i.e. water, wet areas, vegetation, open areas and urban areas. The water class includes the areas with sufficient visible flowing or standing water. The wet class was assigned to those areas which did undergo some amount of flowing water or partial accumulation for a short period of time. On the image acquisition date, these areas show wet and high moisture conditions which are not considered to have caused any damage to the land cover. As the study objective is to map the flood extent, assess damages and map floodplain boundaries, classification results for only two classes i.e. Water and No Water were used. All classes other than water were combined as No Water class. A multi-temporal post classification approach was applied in order to assess the pre and post flood changes between the two images and to produce change maps. The change map shows before and after floods in the extent of water bodies and to locate the most flood prone areas. The visual analysis of the flood image revealed the most serious flooding along the river courses as compared to other land areas. The same observation was verified by the change map. This change map helped to quantify the areas subject to flood. These classification results were then converted to shape files for further analysis and assessment through GIS. The analysis of water classes for both years and related statistical results show an increase of about 93,000 hectares (9%) of area subject to flood waters. The worst hit and most affected counties were Knox, Daviess, Greene and Vigo mainly from the overflowing river water. Knox County was mostly affected by White river as it flows all along its eastern and southern boundary. However, Wabash River on its western border badly hit Illinois state areas and less area of Knox County. Daviess County had the flooding mainly from White River and East Fork White River. The summary and comparison of each county's area subject to floods are shown in Table 1.

The change detection to assess flooding in urban areas was however limited by the low resolution (30 m) of the images. Figure 5 below shows the classification results for both years and the change map for flood water. The red color in the change map indicates the excess water to that of year 2007.

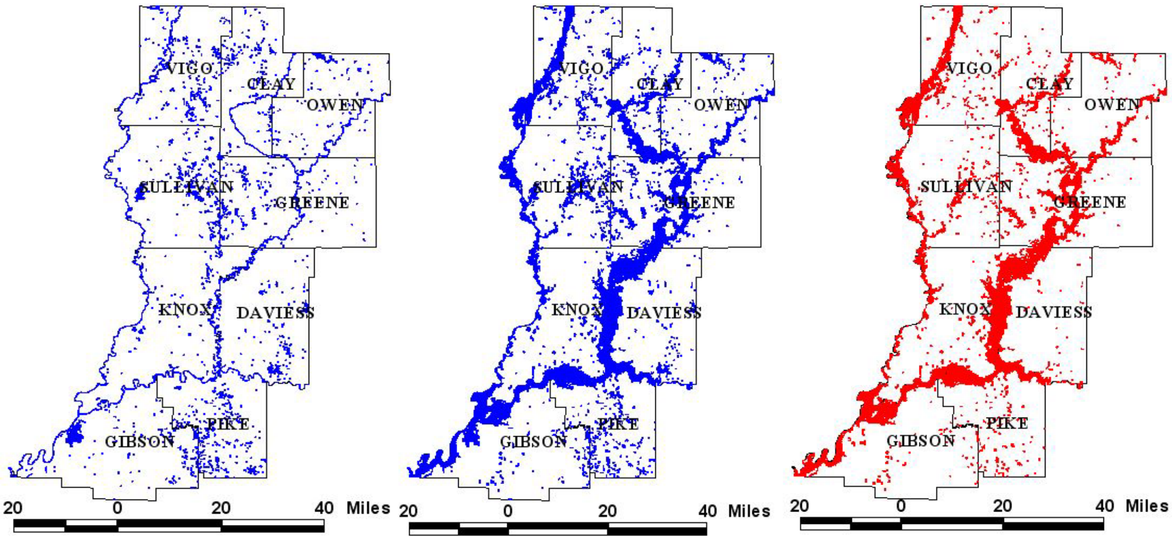


Figure 5. Water in Year 2007 (left), 2008 (middle), and the change map (right).

Table 1. Overall county area vs areas under flood water

County	Area (Hectares)	Flooded area (Hectares)	% Flooded area
Vigo	106223.63	10208.81	9.61
Clay	93237.00	8271.91	8.87
Owen	100316.70	4359.36	4.34
Sullivan	117464.82	6714.66	5.71
Greene	141291.13	14534.00	10.15
Knox	135653.03	20637.82	15.21
Daviess	113003.90	12708.89	11.24
Pike	88302.33	5994.00	6.79
Gibson	129159.44	9939.98	7.70

DAMAGE ASSESSMENT

The post classification results were used in GIS to estimate the damages to the standing crops, the roads submerged under flood water, and the areas out of the designated floodplains. The details of the analysis procedure and data used are described below.

Crops Damages

Every year the United States Department of Agriculture (USDA) along with National Agricultural Statistics Service (NASS), Farm Service Agency (FSA) and participating State governments record and produce digital data layers named as “cropland data layer (CDL) for the major crops [5]. This data layer is suitable for use in GIS applications for analysis purpose. The CDL program annually focuses on corn, soybean, and cotton agricultural regions in the participating states to produce digital categorized geo-referenced output products for crop acreage estimation. For this purpose the Indian remote sensing satellite ResourceSat-1 (AWiFS - 56 m) imagery [6] and FSA registered grower’s reported field data is used [7].

For this study, latest available crop data layer was for the year 2007. This data was used to estimate the areas that were under crops last year in these counties and compared with the areas that were under flood this year. The CDL contains records of number of crops, however for this assessment only the major crops grown in the study area were used. It includes corn, soybean, wheat, pasture /hay and forest/shrubs land. The areas under these crops for the year 2007 were calculated from this data using GIS analysis tools. It was assumed that the same areas were under the same crop this year as for the CDL year-2007. Based on this assumption, all the crops damage estimation was made by comparing each crop area with the flood data layer. This damage estimation was made for each county separately. Most of the agriculture area in these counties was under corn and soybean and less to other crops, resultantly more damages were also to these crops. Mostly the crops areas along the river courses and floodplains were affected. The CDL 2007 and the same with 2008 flood extent overlay are shown below in Figure 6.

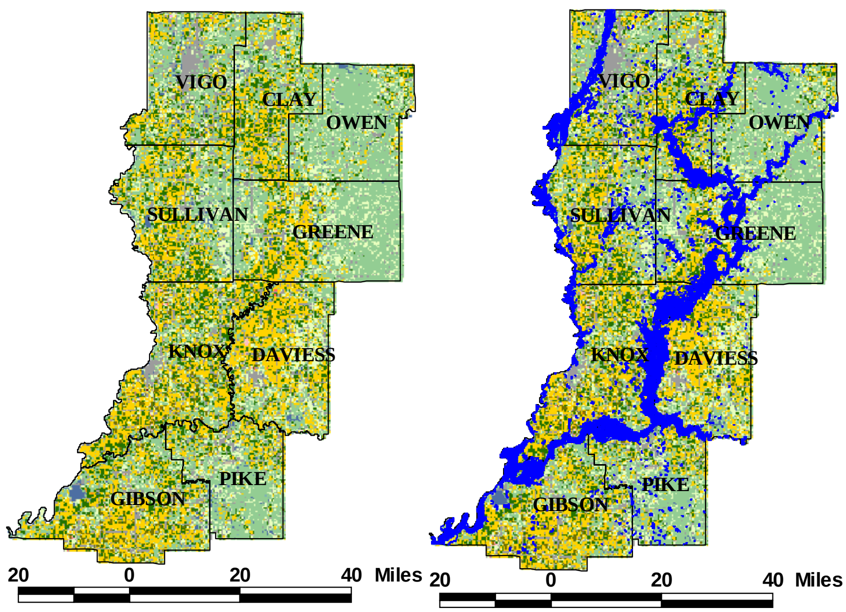


Figure 6. Crops Data Layer 2007 and the same with June 2008 flood extents overlay (courtesy USDA, NASS).

The analysis of the crops damage statistics indicate that corn and soybean had the higher percentage damages in almost all these counties with an average of about 15.5 % each. The crops in the Greene County are badly hit with the highest percentage damages of 31% corn, 23% soybean and 18% of wheat. Other highest percentage damages to corn and soybean are in Knox, followed by Daviess and Vigo counties. There are least damages to crops in Sullivan County. It is because the flood water in Wabash River flowing along Sullivan County’s western boundary caused more inundation to Illinois state area. The summary of percentage crops damage estimates and crop areas under floods for each county are shown below in Figure 7 and Table 2, respectively.

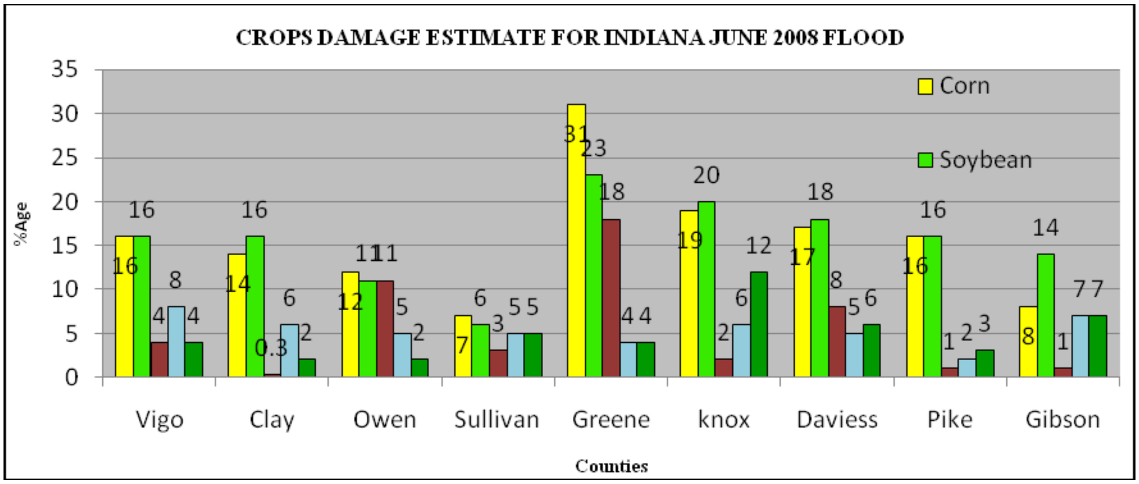


Figure 7. Crops damage estimates for nine counties in Indiana.

Table 2. Crops areas under flood water in each county

	Crops Area under flood water (Hectare)				
County	**Corn**	**Soybean**	**Wheat**	**Pasture, Hay, Grass**	**Forest, Shrubs**
Vigo	3433.91	2480.58	16.57	1005.67	1389.36
Clay	3512.74	2842.43	14.41	843.10	668.00
Owen	1326.77	627.42	49.86	771.43	1375.58
Sullivan	2071.00	1080.13	40.46	789.23	1759.27
Greene	6569.62	2834.42	69.69	1000.63	2487.72
Knox	9234.10	5299.93	132.17	579.29	2406.40
Daviess	6406.31	2646.57	132.18	1118.35	1192.62
Pike	2364.52	1393.75	5.31	228.21	1558.00
Gibson	3498.98	2523.37	68.46	715.55	2161.11
Total Area	38418.00	21728.60	529.12	7051.46	14998.00

Based on the above statistical results the crop damage estimation map, Figure 8 is created that shows the distribution of floods affected crop areas in each county of the study area.

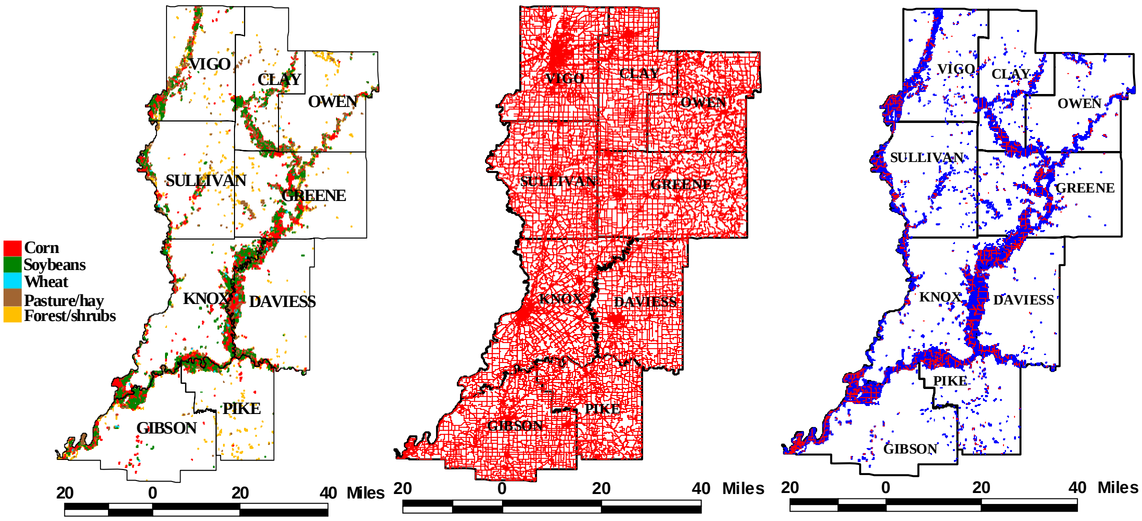


Figure 8. Crop damages, (left), road (middle), and road under flood water (right)**.**

Road Damages

For the damage assessment to the roads and street in these counties, Indiana Department of Transportation (INDOT) roads and streets 2005 data layer [8] has been used. Firstly, the length of the roads with in each county was calculated from the INDOT layer and then these roads were compared and checked with the flood water classification layers. Some of the roads observed under the flood waters may not be accurate as the width of some roads may not commensurate with the image pixel size. Even if the road is higher than the adjacent land, it is counted as flood category since its width is too small and its adjacent land area is under flood. Figure 8 show the INDOT 2005 roads and the part of these roads under flood water.

The analysis of these results revealed that mostly the roads passing through the floodplains are affected. A large number of streets and small roads (private and others) are also affected. In addition, a number of State Highway and US highways passing through these counties were also subject to these flood waters. State road 57-157 was most affected, a total 13 km of this road segments came under flood at different locations followed by state road 59 (6.8km).Overall about 37 km of different State Roads category were affected. Out of US Highways, US -231 was most affected as a total of about 12 km of its segments were subject to flood water. This analysis shows that the most affected are the County Roads. Figure 9 below show the statistics of these flood affected roads in each of these nine counties.

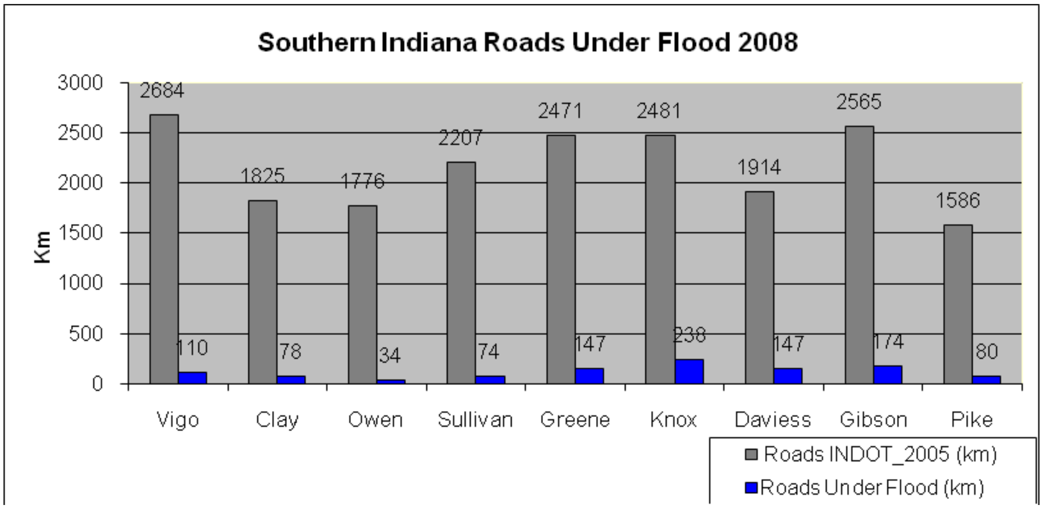


Figure 9. Roads and streets in counties and affected by flood water.

Floodplain Changes

Floodplains are defined as those land areas situated adjacent to rivers and streams that are subject to recurring inundation [9]. The extent of these floodplains are marked and designated based on the analysis of occurrence of floods into the rivers and streams and the overflow of its water to the adjacent land over a long period of time. Generally, the water on the floodplain usually drains back to the water course as its flow recede. However, for places where the water course has higher banks as compared to floodplain level, the water may not drain back and cause inundation or pounding over a longer period of time thus making the area unusable for any activity. The analysis of every flood through remote sensing data acquired during the peak time can help greatly to examine, inventory and incorporate changes to the extents of these floodplains and other flood prone areas. The analysis and comparison of the recent flood extent to the designated floodplains show that most of the flood waters remain within the floodplains, however it did overflow the boundaries of these at few places (Figure 10, red areas) due to high water levels in the rivers. It mostly happened in White River floodplains in Greene and Daviess counties and in Wabash River in Knox County. These general pre-designated floodplains [10] and the 2008 flood water overlay are shown in Figure 10. The pink color shows the floodplains extents, blue the 2008 flood extents, and the red the flood extent over and above the floodplains.

Discussions

Rainfall data for the first week of June 2008 and the river gauge station readings when compared to previous years data clearly show the severity of the floods. The medium spatial resolution (30m) Landsat multispectral images proved to be useful data source for mapping flood extent and estimating damages to major crops and floodplains. The flood extent has been very effectively mapped using temporal satellite image data. The spatial distributions of estimated damages show a high concentration of losses to crops along the rivers and streams. Southern Indiana has a variety of summer crops, and corn and soybeans were the most affected i.e. about 15-16 % losses as compared to 2007 crops data. A large number of roads segment(totaling about 1,100 km) in almost every county were submerged under water, including State highways, US roads, county roads and many other small roads, with the most affected being the county roads. The flood water did spill over the designated floodplains at a few places generally along the river courses. Greene, Knox, Daviess and Vigo counties were the badly affected by the overflowing Wabash, White and East Fork White rivers. The damages were mainly focused to the broader categories in this study, however, if detail property GIS data is integrated, the crops damage estimation could be enhanced to the level of individual property, farm and owner.

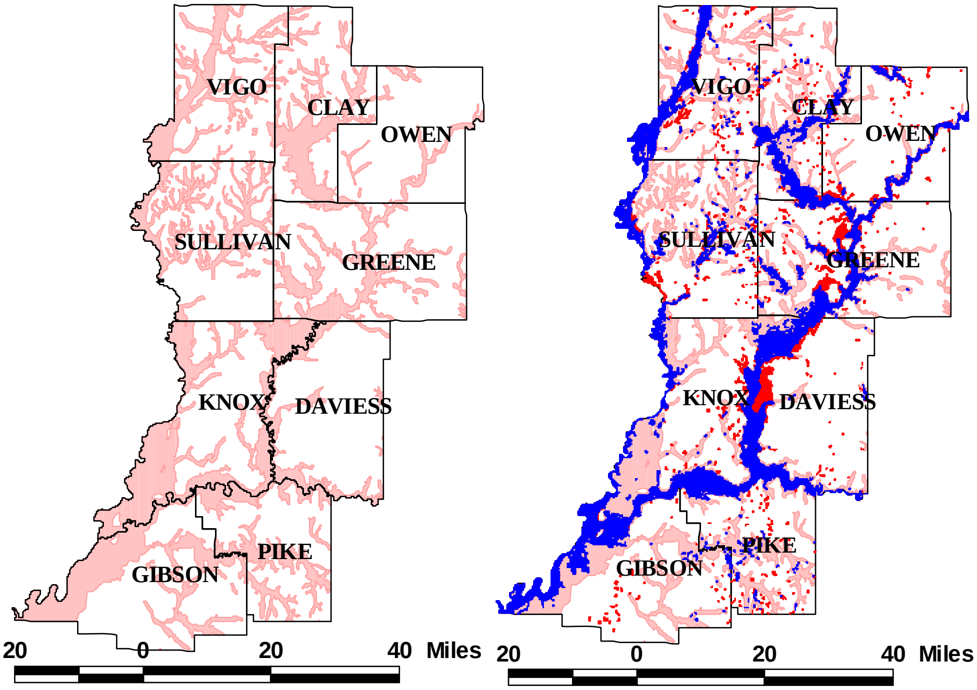


Figure 10. General floodplain boundaries (left) and flood water within (blue) and outside (red) the floodplains (right).

FLOOD MAP PUBLISHING

Google Earth Plug-in and API

Google Earth plug-in released in June, 2008 is the Web version of Google Earth desktop that enables us to embed Google Earth functionalities into our own sites. Using Google Earth plug-in, we do not need to install Google Earth to use virtual globe and we can easily publish the flood maps through the Internet along with satellite images, roads, terrain, and 3D visualization. Google Earth provides java script library, called Google Earth API, which allows us to add Google Earth plug-in objects into our own sites. Google Earth API also enables us to access plug-in objects and features imbedded in them. Using the API, we can publish geographic information, draw point markers, lines, polygons and add vector layers or drape raster layers onto the Google Earth. To develop a site using Google Earth plug in and Google Earth API, we need to get Google Maps API key from Google web site. This API key should be added to the <head> section of page to be published.

The basic format of Google Earth plug-in is KML or KMZ where KMZ includes any icons and images referenced in the KML file. KML (Keyhole Markup Language) is an XML-based language schema for displaying and visualizing geographic data. To display the existing vector GIS data in Google Earth, we need to convert it into KML format which can be done through commercial GIS software and freeware or commercial conversion software. Most commercial conversion program usually provide more convenient interface and various functions to enhance the visual effect of the data.

Flood Data in Google Earth

Using Google Earth API we uploaded both pre and post flood extent classification results for the whole Landsat scene and were available to users with a week of the floods. Later on, damage estimation layer for each crop type in the study area was added. This information can be displayed separately or in combination with other layers. In addition to geospatial data viewing, the statistical summary of the damages was also made available on the Web. This arrangement and provision of data along with Google basic topographic data help the authorities to analyze the real flood situation quickly. A screen shot of the developed web interface loaded with 2008 flood extent (red color) and cropland data layer 2007 draped over the Google base image is shown below in Figure 11 (https://engineering.purdue.edu/CE/Academics/Groups/Geomatics/floodmaps/2008_flood_map.htm).

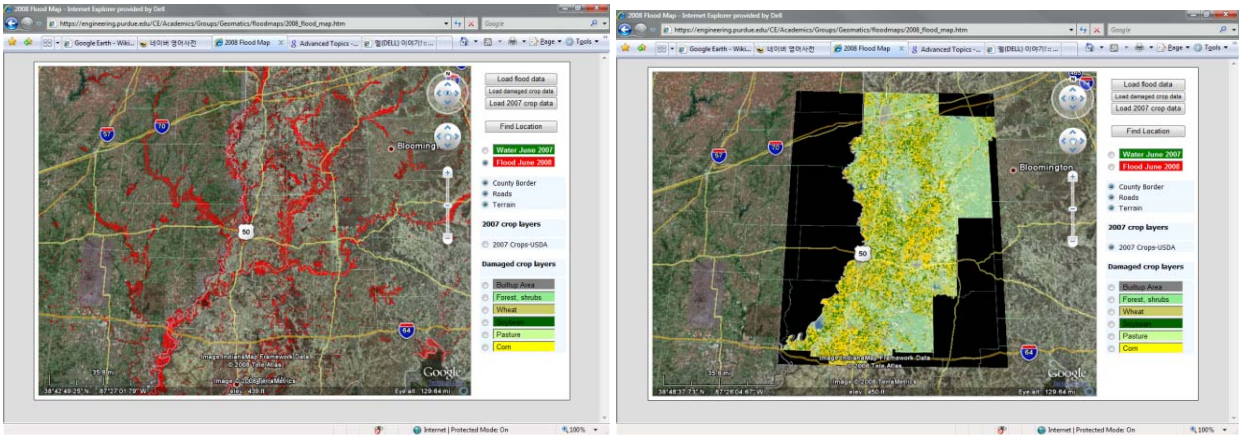


Figure 11. Flood mapping (left) and crop damage (right) with overlay of Google Earth base data.

CONCLUSIONS

The primary objective of the use of remote sensing data for mapping and the publishing on the web of widespread natural disasters is to provide the planners and disaster management institutions with a quick view of the ground conditions and disaster impact. Its timely availability on the internet and to the disaster management authorities help quickly visualize the disaster impact and support their disaster response activities during and after the flood. This information can also help them make a quick response plan and move swiftly to take appropriate remedial measures. It can help the residents in the flood affected areas visualize and assess the amount of flooding and losses to their property.

The use of satellite remote sensing image data is proved to be very helpful during recent Indiana floods for rapid mapping of the flood extent. The medium resolution imagery can help for mapping broader disaster impact. However, its constraint is its inability to detect fine level changes, as it is only capable to detect changes at bigger levels. The availability and use of higher resolution data augmented with ancillary GIS data will allow us to assess flood damage at more detailed level, including the damages to urban areas. The addition of digital surface models can be used to model flooding process to provide valuable information for planning and design of flood protective infrastructure.

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