GEOMATICS IN HYDROLOGICAL SIMULATIONS: THE ILIGAN EXPERIENCE

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ABSTRACT

The increasing rate of urbanization and population rise in the Philippines places an increasing demand on the basic services of the different government agencies. Managers desire better ways to incorporate geospatial information in their decision-making processes. One of the more common applications of remote sensing in the Philippines is in the field of disaster management, particularly in the study of extreme rainfall effects.

Remote Sensing (RS) applications to hydrological problem solving have successfully transitioned from being experimental to operational in the last couple of years, and information gathered through these technologies can facilitate water resource procedures. Configurations from RS imagery can be translated into a deterministic distribution of input data over a wide area on a pixel-by-pixel basis. This paper presents the application of watershed characterization methods and the integration of satellite-derived information from Remote Sensing (RS), and Geographic Information System (GIS) visualization and simulation capabilities in improving hydrologic estimation processes.

Keywords: Classification, Integrated Remote Sensing and GIS analysis, Flood/Drought

INTRODUCTION

Remote sensing is defined as the “branch of science which derives information about objects from measurements made from a distance i.e. without actually coming into contact with them.” (Navalgund, 2001). Researchers around the world have studied the potential use of remote sensing to obtain accurate information about watershed hydrology (Cashion et al 2005). Bhavsar's (1984) work includes hydrologic parameters estimation using the early generations of Landsat, aircraft-based remote sensing equipment, and their coun-try's (India) very own Bhaskara I and Bhaskara II. Milewski et al (2009) applied techniques for rainfall–runoff and groundwater recharge estimation in arid areas using information from multiple remote sensing satellites. They concluded that their regional remote sensing-based approach must not be considered as a replacement to traditional methodologies that rely on extensive field measurements, rather, it should be treated as a first-order alternative for gathering information in areas lacking in spatial and temporal precipitation and field data. Schultz (1997) studied the use of remote sensing in agricultural water management. He identified real-world problems such as water supply estimation that remote sensing could solve and illustrated the practicality of the available information from space.

The Philippines is known to be one of Asia's typhoon entry points. In the midst of climate change debates and the increasing occurrence of extreme events, control measures and estimation systems play an increasingly critical role in disaster preparedness through improving flood alleviation procedures (Roaf et al., 2005). From our own experience during Typhoon “Ondoy” and especially Typhoon “Pepeng” events of 2009, the maturity of estimation and forecasting of parameters in both weather and catchment inflow can improve the reaction time for evacuation and improve preparedness for rescue operations. Recently, the Philippine Government, through its agencies and state universities have been investing in the use of Remote Sensing datasets for flood disaster risk management.

Study Area

The study was done in the province of Iligan. The Iligan River Basin is located in the Southern part of the Philippines. It has an estimated drainage area of 242.5 square kilometres. Iligan City is bounded on the east by Bukidnon; on the west by Iligan Bay; on the north by Misamis Oriental and

Cagayan de Oro; and to the south by Lanao,

Iligan experiences rainfall throughout the year. The distinction of the seasons are not very pronounced. Because of its geographical location and surrounding terrain, the effects of extreme weather disturbances are indirect.

MATERIALS AND METHODS

Multispectral Imagery

We utilized archived GeoTIFF format images of the study area from Landsat 4, 5, 7 and 8 (experimental). They were designed to capture images over a 185-kilometer swath and gather data at an altitude of 705 km. The 30-meter spatial resolution gives sufficient information for the purposes of our study.

Digital Elevation Models

The elevation data that we used for the watershed modelling was derived from the ASTER Global Digital Elevation Model (GDEM). Fortunately, the GDEM from ASTER is recent and electronically released for free to users worldwide from the Earth Remote Sensing Data Analysis Center (ERSDAC) of Japan and from NASA's Land Processes Distributed Active Archive Center (LPDAAC) web servers. The DEM has a 1 arcsecond (approximately 30 meters) spatial resolution in the horizontal plane, which bodes well with that of the Landsat images; hence a good fit of the images draped over the DEM is ensured.

Land Cover Classification

Remote sensing can provide rapid methodologies of land cover mapping and the accuracies of these classifications. These methodologies make use of the way a certain type of cover reacts with light, or its spectral properties.

In this research, we tested four types of supervised classifiers (Parallelepiped, Minimum Distance, Mahalanobis Distance and Maximum Likelihood) and two types of unsupervised classifiers (Isodata and K-means).

We used the Maximum Likelihood Classifier because it produced the highest overall classification accuracy. The classifier assigns the pixels to their corresponding class based on the odds or likelihood that they fit in to that class. The function for each image pixel is calculated by the formula offered by Richards (1999),

$$g_i(x) = -\ln \rho\,(\omega_i) - \tfrac{1}{2}\ln|\Sigma_i| - \tfrac{1}{2}(x - m_i)^T \Sigma_i^{-1}(x - m_i) \qquad (1)$$

where: i = class; x = n-dimensional data (n is the number of bands); $p(\omega_i)$ = probability that class w_i occurs in the image; $|\sum_i|$ = determinant of the covariance matrix of the data in class w_i; $\sum_i^{-1}$ = its inverse matrix; and, m_i = mean vector.

Ground Truthing

Ground truth points were taken from both the initially classified Landsat-7 image and Google Earth. A list of these points' corresponding positions in terms of latitude and longitude were listed down and hard copies were printed out for tracking. Three teams were deployed for the fieldwork.

Not all of the more than 200 points initially identified for ground validation were accessed due to terrain difficulties and security issues. Out of the 200+ points, 134 points were successfully recovered during the field activity. Replacements of inaccessible points were obtained, preferably those near the marked sites and additional points were also obtained for post processing accuracy purposes.

Another issue that we had to tackle in the field is the very thin distinction between what can be considered a forestland and a plantation – some points classified as "forestland" turns out to be a thick "plantation", and some points deemed as "plantation" is in actuality a "forest". There is also the case of the nipa plantation where, while technically a plantation, the necessary ground condition should be that of a fallow land, and thus it is already saturated to be able to accommodate any more water from a rainfall event.

River Cross-section and Profile Surveying

Cross-section surveys (Fig.1) for the Iligan River were also conducted to gather elevations above or below the Mean Sea Level. The cross-sections were saved as shapefiles and projected in UTM Zone 51N WGS-84 Datum for flood modelling purposes.

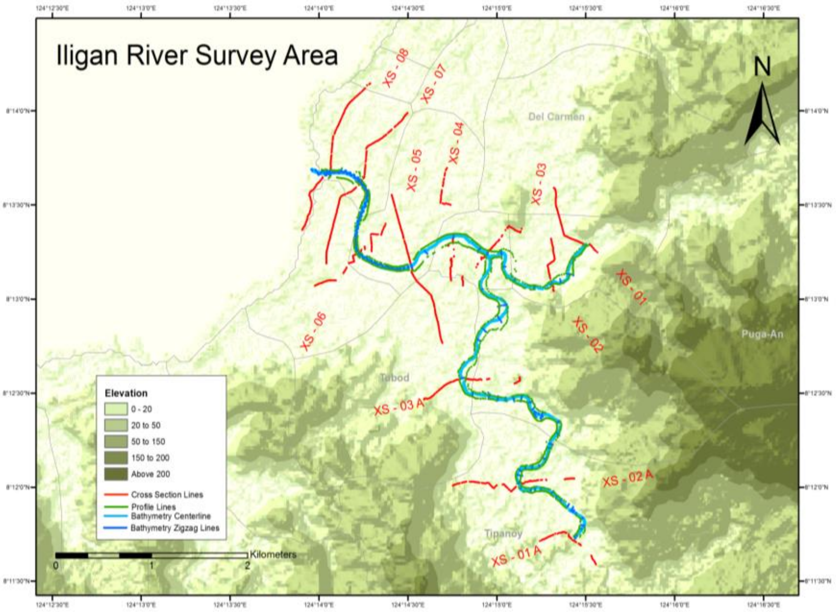


Figure 1. The Iligan River Cross-section Survey Schematic (DVC, 2013)

HEC HMS Watershed Modelling

The Iligan basin model (Fig.2) is configured into 31 subwatersheds, 29 reaches, and 30 junctions. The ASTER elevation data were used for the delineation of these sub-watersheds and the extraction of the drainage network. These mechanisms symbolize the hydrologic network and their connectivity. HEC-HMS® was fed with pertinent Landsat-derived information for the individual sub-watersheds.

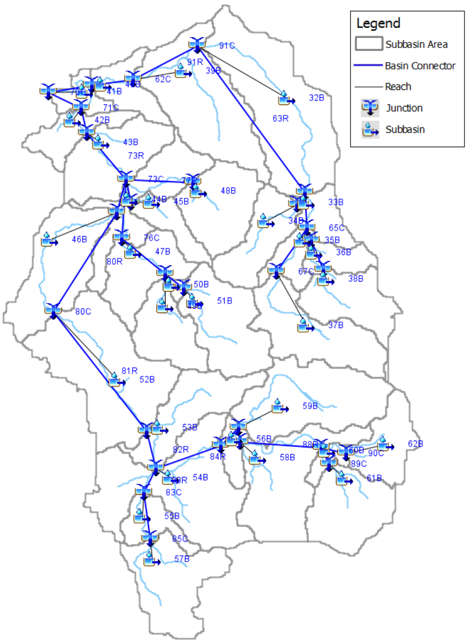


Figure 2. The Iligan basin model generated using HEC-HMS.

In the HMS, we used the Soil Conservation Service Curve Number (SCS-CN) methodology. The NRCS-CN method, more widely known by its older name the SCS-CN method, is a set of empirical mathematical equations that is used to determine the amount of surface runoff. Developed in the United States by the Natural Resources Conservation Service (NRCS), formerly known as the Soil

Conservation Service (SCS), the CN runoff equation assumes that "the ratio of amount of actual retention to watershed storage is equal to the ratio of actual direct runoff to the effective rainfall (total rainfall minus initial abstraction)" (Melesse & Shih, 2002). In mathematical form:

$$\frac{F}{S} = \frac{Q}{P - I} \tag{2}$$

where F = actual retention (mm); S = watershed storage (mm); Q = actual direct runoff (mm); P = total rainfall (mm); and I = initial abstraction (mm).

To derive the runoff Q, the abovementioned formula is expressed in terms of the water balance equation $F = (P - I) - Q$ to derive the relationship:

$$Q = \frac{(P - I)^2}{P - I - S} \tag{3}$$

and plugging the relationship in the previous equation yields:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}, P \geq 0.2S \tag{4}$$

To derive the value of S (since P is obtained through rainfall data) the NRCS published a set of CN values depending on both the type of land cover and the type of soil. In the case of the study, the CN values of the different land cover types per hydrologic soil group are as follows:

Table 1. AMC II Curve Numbers for Different Soil Groups.

Land-use/Land-cover	AMC II Curve Number for Hydrologic Soil Group			
	A	B	C	D
Bare Soil	77	86	91	94
Built-up Area	59	74	82	86
Fallow Land	77	86	91	94
Forestland	30	55	70	79
Freshwater	98	98	98	98
Grassland	39	61	74	80
Plantation/Shrubland	32	58	72	79

The CN values are used in the formula for determining S:

$$S = \frac{25400}{CN} - 254 \tag{5}$$

For a study area with multiple land cover types, an overall CN value can be obtained by the formula:

$$CN = \sum_j CN'_j \frac{A'}{A_j} \tag{6}$$

Where CN' = curve number of a land cover type; A' = area of the land cover type in question; and A_j = total area of the study location.

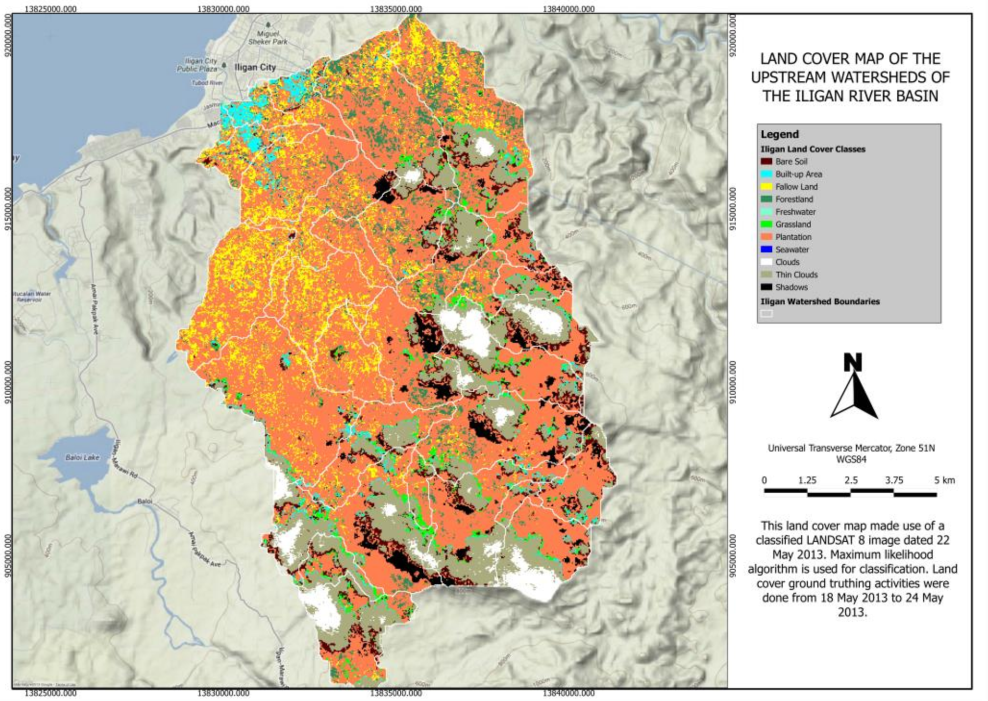
HEC RAS Integration

The Iligan River Flood Model was developed using the Hydrologic Engineering Center River Analysis System (HEC RAS). The purpose of this model is to determine the maximum flood extent and inundation levels due to rainfall events of varying intensity.

The outflow from the watershed model is fed to HEC RAS for flood modelling. This study utilized actual rainfall data and hypothetical rainfall events based on the Rainfall Intensity Duration Frequency (RIDF) curves for Iligan provided by PAGASA.

RESULTS AND DISCUSSION

Classification Results



This land cover map made use of a classified LANDSAT 8 image dated 22 May 2013. Maximum likelihood algorithm is used for classification. Land cover ground truthing activities were done from 18 May 2013 to 24 May 2013.

Figure 3. Landsat 8 Classified Image.

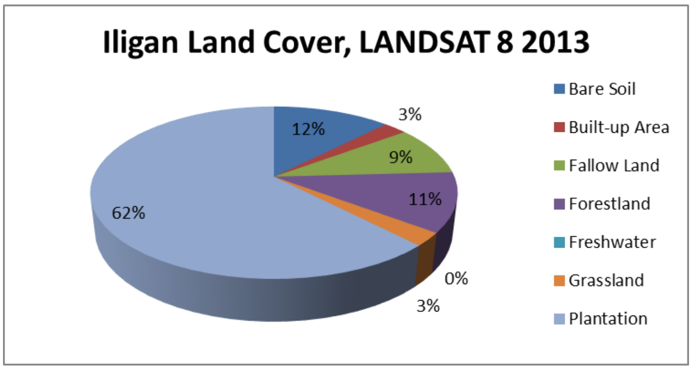


Figure 4. Distribution of Land Cover (in percentages).

Landsat 8 data for the basin became available during the ground truthing activities of the research. Figure 3 shows the Classified (MLC) Image for Iligan. Areas under cloud cover were corrected using secondary information from NAMRIA land cover data (2003); MSU-Marawi forestry department data (2004 & 2006); Classified Archived LANDSAT images; Bureau of Agricultural Statistics crop data (for forest/plantation/grassland) and actual field points. Figure 4 shows the distribution of the land covers. Care should be taken in interpreting the distribution. 62% of the area is classified as plantation, however, “plantation” is more descriptive of the cover’s hydrologic properties rather than on the cover’s actual use.

HEC HMS Results

SCS-CN estimates precipitation excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture. SCS-CN is an event model, meaning, it requires input to establish initial conditions then simulates watershed response during precipitation events. The CN for a sub-watershed is estimated as a function of land use, soil type, and antecedent watershed moisture, using SCS-provided tables. The HEC-HMS model used in this study is evaluated using: The Root Mean Square Error (RMSE) (0.003302723); The Nash-Sutcliffe efficiency (-0.441905501); and the Pearson correlation coefficient (0.870688571) (FMC, 2013). Below are the graphs of the outflows.

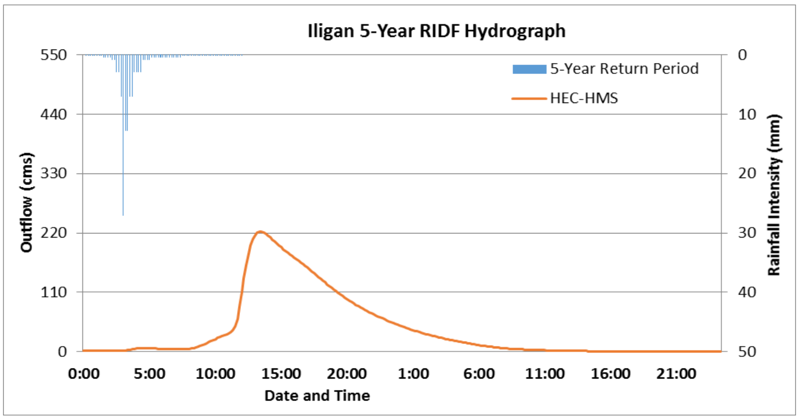


Figure 5. HEC-HMS Outflow hydrograph of 5-Year RIDF (Lumbia station)

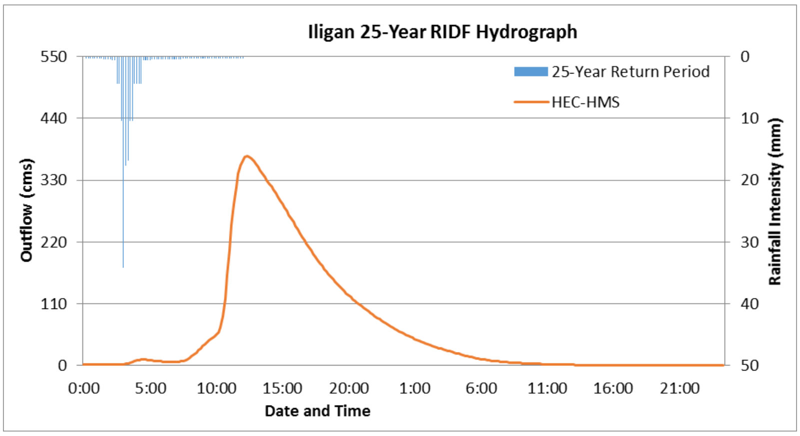


Figure 6. HEC-HMS Outflow hydrograph of 25-Year RIDF (Lumbia station).

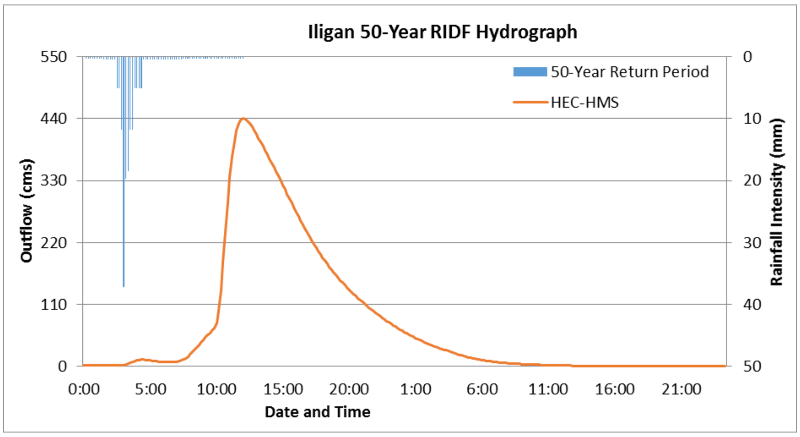


Figure 7. HEC-HMS Outflow hydrograph of 50-Year RIDF (Lumbia station)

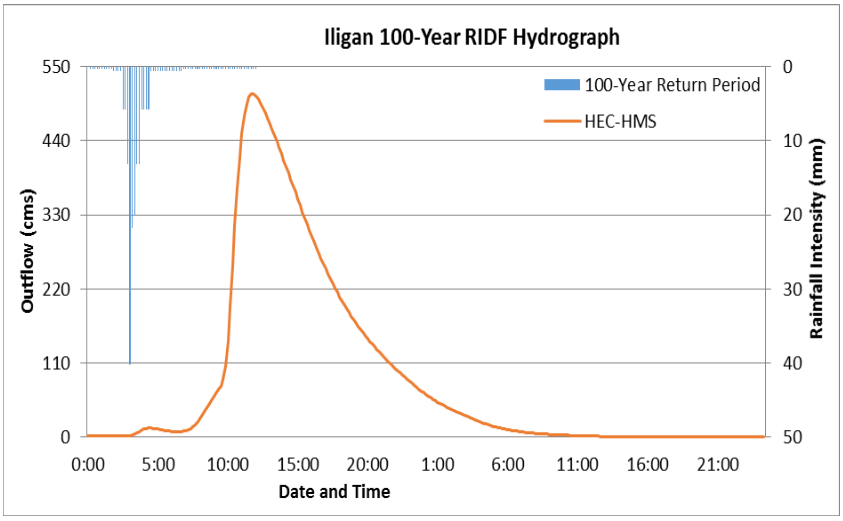


Figure 8. HEC-HMS Outflow hydrograph of 100-Year RIDF (Lumbia station)

Table 2. Shows the summary of the peak outflows.

Table 2. Peak values of the Iligan outflow.

RIDF Period	Total Precipitation (mm)	Peak rainfall (mm)	Peak outflow (cms)	Time to Peak
5-Year	110.4	27.1	222.1	13 hours, 20 minutes
25-Year	148.2	34.2	372.8	12 hours, 20 minutes
50-Year	163.9	37.2	440.5	12 hours
100-Year	179.4	40.2	509.9	11 hours, 50 minutes

In addition, we have also looked into Iligan's land cover change in the context of SCS-CN Hydrologic Modelling. We have identified five (5) subwatersheds with the highest observed Curve Number Change.

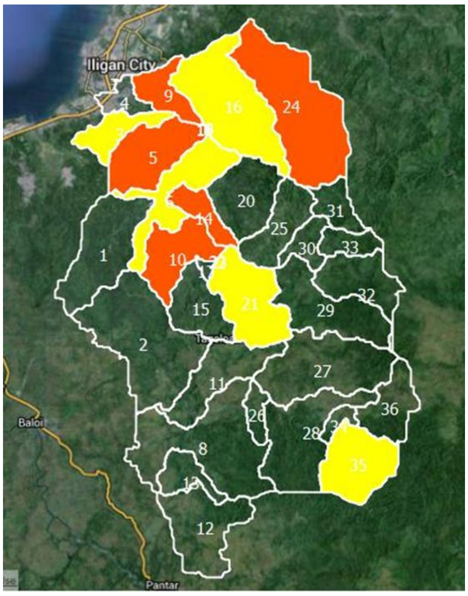


Figure 9. Critical Watersheds based on detected change in Curve Numbers. Top 5 (Orange). Next 5 (Yellow).

CONCLUSION

Remote Sensing provided information which were more spatially descriptive of the hydrologic processes at the watershed scale. Each pixel can contain characteristics that are relevant hydrologically and qualitative interpretation of these information is useful in dealing with the scarcity of geographical data at a regional scale. However extreme caution should be exercised in relying solely on satellite-derived datasets. In practice, all the attributes of each pixel cannot be measured, but remote sensing information maximizes benefit when coupled with field observations to validate and verify accuracy.

An updated source of soil information will also help in refining the watershed models. Hydrologic investigations on the study area that focus on infiltration, percolation and groundwater recharge should be done in the future.

The densification of the watershed's rain gauge network and an increase in the frequency of recording measurements will also refine watershed models. A better system of archiving and securing digital rainfall records is recommended as well. These will also help in assessing the performance of the models used.

The key success of this research lies in taking further steps in realizing the potential of integrating remote sensing in solving hydrological and disaster-related problems. As our country continues to improve its spatial technology capabilities, we should also be vigilant in exploring and implementing new methods to ensure better response and sustainability.

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REFERENCES

[1] Bhavsar, P.D. (1984). Review of remote sensing applications in hydrology and water resources management in india. *Advances in Space Research*, *4*(11), 193-200.

[2] Cashion, J., Lakshmi, V., Bosch, D., & Jackson, T.J. (2005). Microwave remote sensing of soil moisture: evaluation of the TRMM microwave imager (TMI) satellite for the Little River Watershed Tifton, Georgia. *Journal of Hydrology,* 307(1):242-253

[3] Melesse, A.M., and Shih, S. F. (2002) Spatially-distributed storm runoff depth estimation using Landsat images and GIS. *Computers and Electronics in Agriculture* 37, 173-183

[4] Milewski, A., Sultan, M., Yan, E., Becker, R., Abdeldayem, A., Soliman, F., & Gelil, K.A. (2009). A remote sensing solution for estimating runoff and recharge in arid environments. *Journal of Hydrology*, 373(1), 1-14

[5] Navalgund, R.R. (2001). Remote sensing: basics and applications. *Resonance*.

[6] Richards, J.A. (1999). Remote sensing digital image analysis. Berlin, Germany: Springer-Verlag.

[7] Roaf, S., Roaf, S., Crichton, D., & Nicol, F. (2005). *adapting buildings and cities for climate change: a 21st century survival guide*. New York, U.S.A.: Elsevier.

[8] Schultz, G. (1997). Use of Remote sensing data in a GIS environment for water resources management. *Remote Sensing and Geographical Information Systems for Design and Operation of Water Resources*, 242, 3-15.