INTEGRATING TIME SERIES REMOTE SENSING INFORMATION IN SUITABILITY ANALYSIS FOR LAND USE PLANNING

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ABSTRACT

The goal of this study was to inform land use planning decisions by incorporating remote sensing time series data and land cover classifications into a suitability analysis. Trends extracted from land cover classifications between the years 2000 and 2020 informed on general land cover trends occurring in the study area, the THLD District of Ghana. Remotely sensed environmental and anthropogenic variables were combined with road and soil data to form the foundations of a suitability analysis. These classifications were then integrated along with time-series remote sensing variables and road and soil data into the suitability analysis, which analyses the validity of land areas for predetermined uses. The preliminary results of the classification show that urban areas have largely expanded throughout the THLD District, while there have been losses in forested areas. The baseline results from the suitability analysis effectively determined transportation accessibility and soil quality for areas across the THLD District. These results provide a strong foundation for the impacts of land use decisions on land cover and environmental trends.

***Index Terms*—** time series, causal linkages, Landsat, classification, suitability analysis, land use planning

1. INTRODUCTION

In recent decades, rapid urbanization in conjunction with varying environmental patterns have resulted in a need for in-depth analyses in the field of land use planning (LUP). LUP is heavily informed by research into environmental and socioeconomic trends, but there are few applications of remote sensing that directly inform land use decision making. Static land cover (LC) maps have been used to detect LC changes occurring within an area and provide spatial information for LUP [1, 2, 3]. Additionally, environmental trends have been tracked through remote sensing methods to understand ecological conditions of regions [4, 5]. Remotely sensed variables such as night lights, population density, and albedo have been used to identify causal relationships between urban development and environmental changes such as deforestation and climatic deviations [6]. Additionally, land surface temperature (LST) has been determined to be a significant indicator of urban expansion and vegetation loss [7, 5].

A suitability analysis can be performed by incorporating relevant criteria to measure the extent to which a land area is suitable for a designated purpose [8, 9, 10]. This provides insight for LUP based on input variables by mapping the interactions between the variables to determine socioeconomic and environmental impacts of decisions [8, 9, 10]. Current GIS-based LUP systems use static land cover classification (LC) maps - typically from the most recent year - to conduct suitability analysis [11]. However, there is a gap in incorporating information obtained from remote sensing time-series data from past decades to LUP. Through a combined analysis of remotely sensed variables and LC changes, LUP can be informed on a more holistic level with and understanding of the potential environmental impacts of policies. The aim of this project is to integrate time-series remote sensing information with land cover classification over the years 2000-2020 using a suitability analysis for LUP purposes.

2. METHODS

2.1. Study Area

The area used for this study was the Twifo Hemang Lower Denkyira (THLD) District in Ghana. It lies in the Central Region and, as of 2010, had a population of around 170,000 [12]. The climate of this area is tropical, with precipitation peaks in June and October and high temperatures generally ranging between 26°C and 30°C. The natural vegetation in the THLD District is largely semi-deciduous forest, but sections of this land cover have been interrupted by human activities such as farming, mining, and logging [12].

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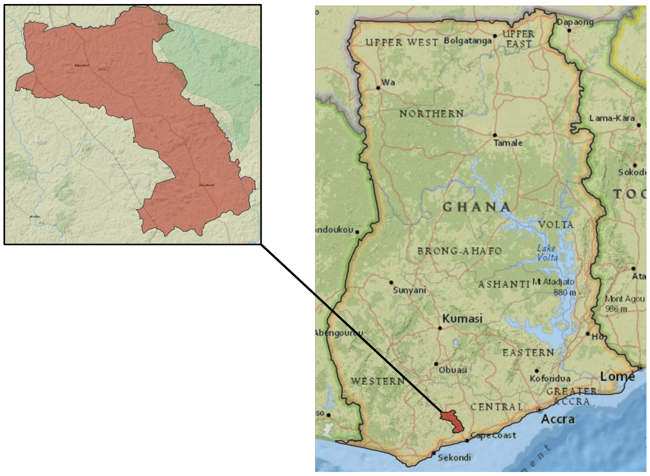

Fig. 1. The location of the THLD district within Ghana.

2.2. Land Cover Classification

LC classification was utilized in this study to examine how environmental conditions have changed over the study period. Randomized points were created within the area of the THLD Distrct using QGIS software, and over 5000 of these points were classified through participants in a capacity-building effort to create training data. For the district-wide classification, Landsat 5 and 8 data at a 30m spatial resolution were extracted from Google Earth Engine, and remote sensing indices such as normalized difference vegetation index (NDVI), enhanced vegetation index (EVI), soil adjusted vegetation index (SAVI), and visible atmospherically resistant index (VARI) were calculated from the satellite data. The Landsat bands and indices were utilized in conjunction with the training points to perform a Random Forest classification in Google Earth Engine for the THLD District. Classifications were conducted for the years of 2000, 2005, 2009, 2015, and 2020.

2.3. Suitability Analysis

A suitability analysis was conducted in QGIS using distance weighting tools developed for LUP [13]. The THLD District was divided into integrated decision units (IDUs) for the purposes of identifying varying suitability levels across the district [13]. The IDUs are representative of homogeneous land areas that were modeled utilizing spatially independent landscape characteristics, which allows for a uniform LUP decision to be applied to each IDU [14, 15]. To determine the proximity of each input variable to the IDUs, the distance from each variable to each IDU as well as the mean variable value within the IDU was calculated [13]. These values were then transformed to a scale of 1 to 9 to match up with the common suitability scale, in which 9 is an indicator of high suitability levels [13]. Each variable input into the suitability analysis was assigned a weighting dependent upon the importance of that variable in the LUP decision, and based on these weights, the values of each variable for each IDU are summed to a score, which is representative of the suitability of that area for the decision [13]. The purpose of the suitability analysis is to then indicate the potential environmental and societal impacts of certain land use decisions. Inputs in the suitability analysis include remote sensing variables of albedo, night lights, population density, and land surface temperature (LST). These variables have been identified as indicators of urban expansion, forest degradation, and climatic variation that are important factors in LUP decisions [6, 7, 5]. This suitability analysis also incorporated socioeconomic and environmental data such as road proximity and soil properties [16, 17]. The complete process of the classification and suitability analysis is given in Figure 2.

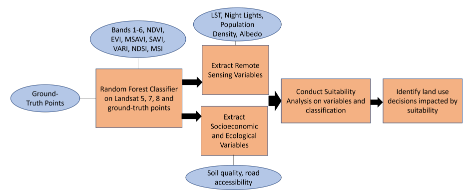

Fig. 2. A flowchart outlining the classification process for years 2000, 2005, 2009, 2015, and 2020 and the suitability analysis.

3. PRELIMINARY RESULTS AND DISCUSSION

3.1. LC Classification

The LC classification results for the THLD District are given in Figure 3. There were small data gaps in the 2000, 2005, and 2009 maps, but the land cover patterns remain evident. Table 1 provides the training and validation accuracies for the classification of each year. All training accuracy values were above 0.9, and all validation accuracy values were within the range of 0.6 to 0.76, indicating a fairly strong classification system. The main trend seen through these classifications is the development of urban areas in the THLD District, which seems to have subsequently overtaken previously forested areas. The maps of 2000 and 2005 depict minimal urban settlements, whereas urbanization has increased by 2009 and continues to grow through 2020. Urban and population expansion has been determined to have a causal relationship with decreased forest densities and increased temperatures, so it can be inferred that the THLD District has experienced these phenomena due to the urban development that has occurred in recent decades [6].

3.2. Suitability Analysis

The baseline suitability analysis provides information on transportation accessibility and soil quality within the THLD

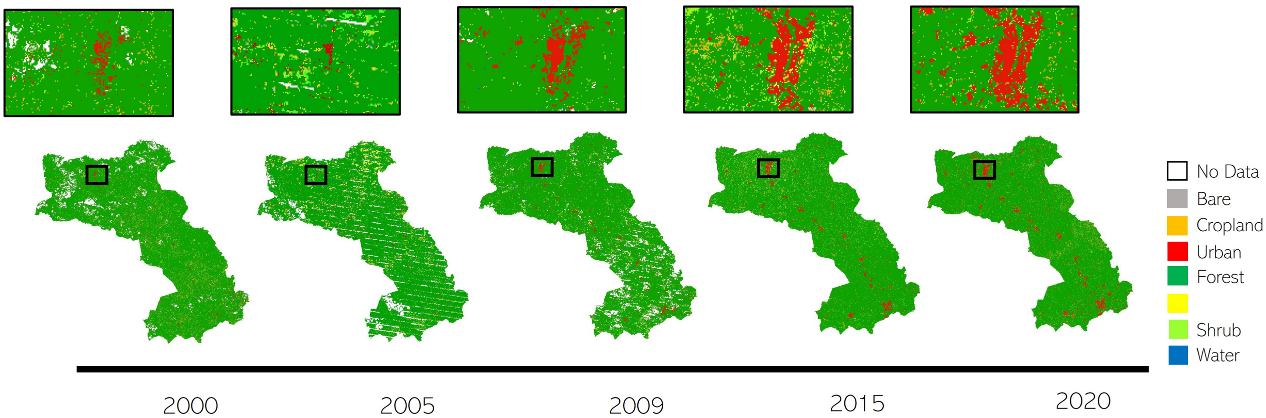

Fig. 3. LC classification for the THLD District of Ghana over the study period.

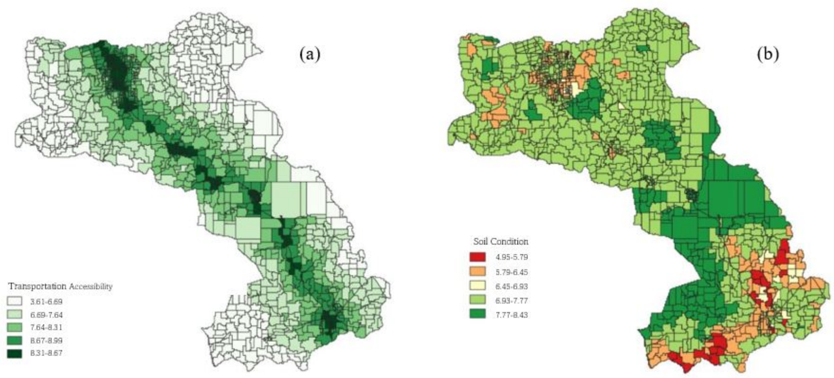

Fig. 4. Suitability Analysis results of (a) transportation accessibility and (b) soil quality in THLD. The suitability scores range from 1 to 9.

Table 1. The training accuracy and validation accuracy levels for each year of LC classifications.

Year	Training Accuracy	Validation Accuracy
2000	0.95	0.69
2005	0.95	0.61
2009	0.93	0.76
2015	0.96	0.76
2020	0.94	0.75

District. These variables provide insight into urbanization and human settlement, as road access and fertile land are essential for the growth of a population. The plot in Figure 4 (a) depicts the availability of transportation for each IDU in the THLD District, and it can be observed that the population residing closer to the middle of THLD have higher transportation access, which can also infer higher urbanization levels [18]. Figure 4 (b) identifies the IDUs with optimal soil conditions, which indcates the suitability of the land for successful crop cultivation. Soil quality appears to be highest in the central areas of THLD, while poor soil quality appears mostly in the South. Additionally, soil quality seems to negatively follow the general trend of transportation accessibility, which is inferred to be representative of urbanization, in both the Northern and Southern regions of THLD, potentially indicating over-use of the land for agricultural or development purposes [19].

4. CONCLUSION

The preliminary results provide evidence for the effectiveness of the suitability analysis method in identifying impacts of interactions between variables within land units. Additionally, the fine-resolution LC classification maps depict urban development that, based on previous work, has causal linkages to remote sensing indices such as night lights, population density, and NDVI [6]. Through a holistic suitability analysis based on the LC maps, socioeconomic data, and remote sensing variables, gaps in LUP can be filled and predictions of environmental and societal impacts of policies can be more informed.

5. REFERENCES

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