Monitoring the Impact on Paddy Fields during the Construction of the Southern Expressway using Remote Sensing and GIS

JAHD Jayasooriya [1#], KA Dinusha [1], GP Gunasinghe[1] and AKRN Ranasinghe[2]

[1]Faculty of Built Environment &Spatial Sciences, General Sir John Kotelawala Defence University, Sri Lanka
[2]Faculty of Geomatics, Sabaragamuwa University, Sri Lanka

35-sursc-0005@kdu.ac.lk

Abstract— *Paddy production in Sri Lanka holds immense significance as a critical agricultural sector that sustains the country's population by providing rice, a staple food. Understanding the fluctuations in paddy land area is crucial since it directly influences paddy production, making it a vital national endeavour. In this regard, the primary focus of this investigation centres around examining the diminishing extent of paddy land area within the Hambantota district. This reduction can be attributed to the construction of the southern expressway, and to unravel this relationship, remote sensing methods have been employed. To assess changes in paddy land area, Landsat images spanning the years 1990 to 2022 were utilized, enabling a comprehensive analysis of the Hambantota district. The outcomes of this study have uncovered a conspicuous decline in paddy land area in close proximity to the expressway during the study period. As one moves away from the expressway, a gradual increase in paddy land area becomes evident. This pattern underscores the transformative impact of infrastructure development on the agricultural landscape. The implications of these research findings extend beyond their immediate significance. They furnish valuable guidance for future construction projects across Sri Lanka, encompassing the construction of expressways, as well as railroads. By integrating these insights into the planning and execution of such projects, adverse environmental impacts, particularly the destruction of paddy lands, can be effectively mitigated. This serves as a vital step toward achieving sustainable development and safeguarding the country's agricultural productivity. Finally found that the beginning of the construction period, there has been a decrease in paddy land area and at the end of the construction period the paddy lands are increased in a decreasing rate. The reason for the increase of paddy lands can get as the encouraging cultivation programs by the government at the end of the construction period.*

Keywords: Agriculture, Landsat imagery, Paddy Land, Remote Sensing

I. INTRODUCTION

Paddy production in Sri Lanka is a key agricultural sector and plays a crucial role in providing rice, which is the staple food for the country's population. Paddy, the primary crop in Sri Lanka, has recorded an annual production of 4.8 million tons, covering a land area of up to 1.09 million hectares (Profile, 2019). Paddy cultivation occurs during two main seasons, namely the Yala season and the Maha season. Additionally, paddy cultivation takes place across all districts in Sri Lanka. In the case of the Hambantota district, it significantly contributes to the overall paddy cultivation in the country (Rajapaksa and Karunagoda, 2009).

Due to the construction projects implemented in the Hambantota district over the past decade, the environment has been significantly affected. The adverse impacts include the loss of land for wildlife, reduction in cultivable land, climate change, and displacement of local communities from their ancestral homes (Kusuma and Pradesh, 2016). Among these issues, the loss of paddy lands poses a major concern as it directly affects the food supply for the country's population. The construction of the expressway, in particular, has resulted in the destruction of numerous paddy fields, as reported by local residents (Song et al., 2016). It is crucial to investigate this loss of paddy land area in order to understand the extent and implications of the damage caused. Conducting such an investigation through traditional field methods, including questionnaire surveys and land surveying, would be expensive, time-consuming, and require substantial manpower. Therefore, the remote sensing method using satellite imagery has been chosen as an alternative approach for this investigation.

The main objective of this research is to investigate the reduction in paddy land area within the Hambantota district resulting from the construction of an expressway. This investigation employs satellite imagery, Remote Sensing technology, and buffer analysis techniques, as described by Song et al. (2016). Furthermore, the findings of this research can provide valuable guidance for future construction projects in Sri Lanka, such as expressways and railroads, enabling them to minimize their adverse environmental impacts, particularly the destruction of paddy lands.

II. METHODOLOGY AND EXPERIMENTAL DESIGN

This chapter outlines the overall approach and methods employed to complete this research analysis. It primarily includes details regarding the study area chosen for this research, the type of research conducted, the research design, tools and procedures utilized, and the sources employed to complete this analysis.

Study Area

Hambantota district is situated in the Southern province of Sri Lanka. It covers an area of 2,496 km^2 and the district lies approximately 10 m above Mean Sea Level (MSL) (Figure 2.1). The average annual temperature in Hambantota district is 27.1 °C (80.8 °F), and the precipitation in the area amounts to about 1063 mm per year. The major soil type found in Hambantota district is paddy soil, and the natural conditions are highly favorable for agricultural production.

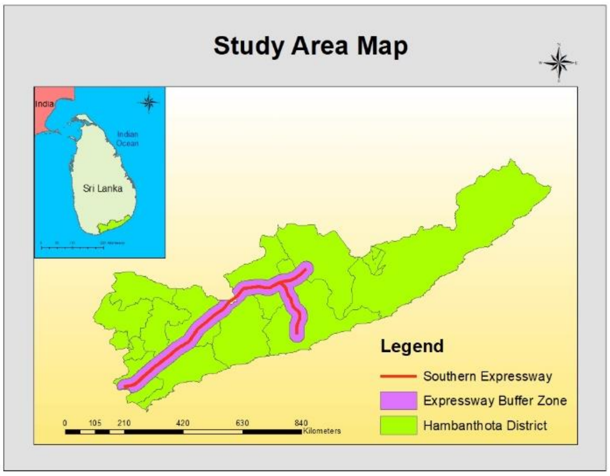

Figure 2.1: Study Area map of Hambantota District

Data Sources

Table 2. 1: Data Sources Table

Secondary Data	Data Source
LANDST satellite images	USGS Earth explore
Google Earth images	Google Earth Pro
Paddy cultivation data	Department of Census and Statistics
Population data	Department of Census and Statistics

Hardware and Software

The following software was used to analyze the data in this research project and obtain crucial outcomes that are vital for decision-makers.

1) Arc GIS software
2) Excel
3) SPSS software

Research Model

This is a quantitative analysis that utilizes secondary data. It can be identified as correlational research. The methodology employed in this research is depicted in Figure 2.2.

Methodology

Change detection of paddy lands area

To determine the changes in paddy land area, satellite images of the Hambantota district were downloaded from the USGS Earth Explorer for the years spanning from 1990 to 2020. Once the satellite images have been obtained, it is essential to perform image preprocessing to enhance their interpretability. Image preprocessing primarily entails geometric and radiometric calibration (Pre-processing, 2015).

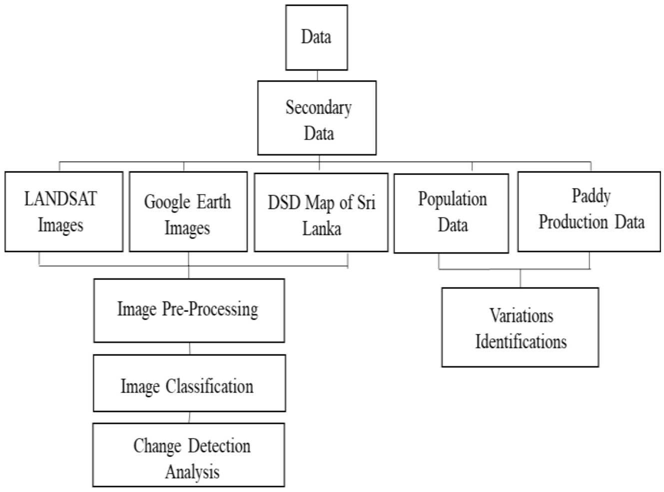

Figure 2.2: Experimental workflow

There are several types of satellite image collections available on the USGS Earth Explorer platform. The downloaded satellite images belong to the Collection 2 Level 2 category. These images have already undergone geometric and radiometric corrections (Landsat Collection 2 Level-2 Science Products, 2013). Therefore, there is no need to perform those corrections again on this particular type of satellite image.

When considering satellite images, it is important to note that LANDSAT 8 images have been available since 2013 on the USGS Earth Explorer platform. Prior to 2013, from 1990 to 2012, LANDSAT 4-5 images were utilized. Moreover, for the purpose of identifying changes in paddy lands, LANDSAT images with a resolution of 30 m are being considered.

After completing the aforementioned process, image processing was conducted using ArcGIS software to identify the changes in paddy lands over a span of 30 years. The satellite images were classified using various methods available, with a focus on unsupervised classification and supervised classification. In unsupervised classification, the software itself determines the number of classes, whereas in supervised classification, the user defines training samples to instruct the software on selecting specific types of pixels for particular land uses (Kusuma and Pradesh, 2016b).

The supervised classification process involved selecting pixels from known land use classes to create training sites, referred to as signatures, for each class. It is crucial to carefully select testing sites to accurately assess the classification results. In this study, the supervised classification approach was employed, and over 50 training samples were chosen for each land use type. Subsequently, by utilizing cell values, the areas of paddy lands were calculated for each year, and these data were utilized to determine the extent of changes in paddy land area (Abd and Alnajjar, 2013). Further, the land use types were categorized into six classes, namely paddy, urban, marshy, forest, other, and water (Kusuma and Pradesh, 2016b).

After completing the classification process, it is crucial to validate the results through accuracy assessment. This step is vital as it provides evidence to support the correctness of the classification outcomes. In this case, the classified image is compared to another reliable data source, known as ground truth data. Due to limitations in accessing real ground data, the comparison is performed using Google Earth images.

To conduct the accuracy assessment, random sampling of reference points is carried out utilizing Google Earth Pro. The comparison between land use types and the reference points is accomplished through the use of a confusion matrix, which allows for a detailed analysis of the agreement or discrepancies between the classified results and the reference data (Utami and Ahamed, 2018). It is important to note that, for the purpose of further analysis, the focus is solely on the paddy field class, and therefore, other land use types are not included in the analysis.

To identify the buffer area that significantly affects the changes in paddy lands as a result of expressway construction, a buffer zone was established. According to Song et al. (2016), this buffer area extends 2 kilometers on both sides of the expressway. Once the buffer zone was identified, it was clipped with classified images to determine the extent of paddy land within each image. In addition, Google Earth images were digitized to obtain data on the specific sections of the expressway located in the Hambantota district.

Furthermore, population data and paddy production data were obtained from the Department of Census and Statistics. The variation of these data was analyzed using Excel software.

In this study, the paddy area was calculated for five-year intervals. This decision was made due to the presence of significant cloud cover in a considerable number of the downloaded satellite images from the Hambantota district. The cloud cover obstructed clear visibility of the areas of interest. Thus, a five-year interval was determined as the minimum time period that offered satellite images with minimal cloud cover.

Relationship between Distance from the Expressway and the Paddy Land Area

Furthermore, the created buffer was divided based on distance, and the correlation between the distance from the expressway and changes in paddy land was examined. This analysis aimed to determine whether these changes exhibited a strong or weak increase or decrease. Additionally, Google Earth images were digitized to obtain data specifically for the expressway section located within the Hambantota district.

Further investigation was conducted to analyze the impact of increasing distance between roads and paddy lands. Additionally, the study aimed to determine the area of paddy lands at 500 m intervals within the buffer zone area located 2 kilometers away from the expressway. The area of paddy lands at each distance was determined by creating buffers.

Pearson's correlation coefficient is a statistical measure used to assess the relationship between two continuous variables (distance versus paddy land area). It is widely recognized as the most reliable method for determining the association between variables of interest, as it is based on the covariance method (Correlation Coefficient: Simple Definition, Formula, Easy Calculation Steps, 2021). This coefficient provides valuable insights into the strength and direction of the relationship. Based on the formula, the coefficient values range from -1 to +1, as illustrated in Figure 2.3. These values indicate the magnitude of the association between the variables.

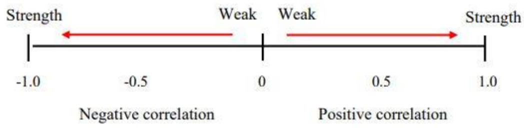

Figure 2.3: Coefficient values variation

The methods and procedures outlined above represent practical steps that can be taken to address research questions.

III. RESULTS

The following analysis focuses on the fluctuations in paddy cultivation across the entire Hambantota district between 1990 and 2020, with data collected at five-year intervals (Figure 3.1).

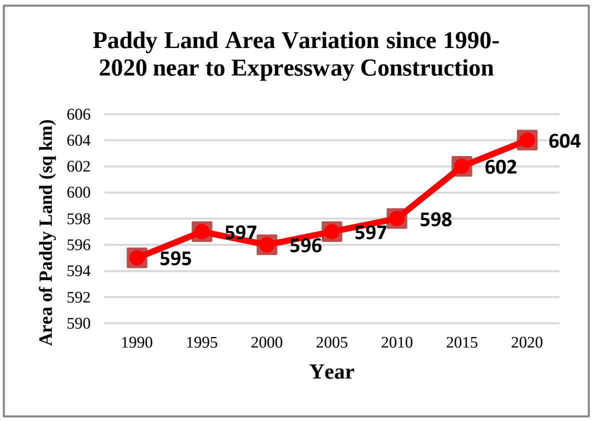

Figure 3.1: Paddy land area variation from 1990-2020

Between 1990 and 2000, there was a slight fluctuation in paddy land area, with values ranging from 595 km^2 in 1990 to 596 km^2 in 2000. These variations were relatively minor, indicating a relatively stable paddy land area during this period. From 2000 to 2010, the paddy land area remained relatively constant, with values consistently hovering around 596 km^2 to 598 km^2. This suggests a period of stability in paddy cultivation within the district. However, starting from 2015, there was a noticeable increase in paddy land area. In 2015, the area expanded to 602 km^2, indicating significant growth compared to the previous years. This trend continued, with the paddy land area reaching 604 km^2 by 2020, marking a further expansion.

Figure 3.2 represents the variations in paddy cultivation within the buffer zone adjacent to the expressway in the Hambantota district from 2015 to 2022, with annual data collection.

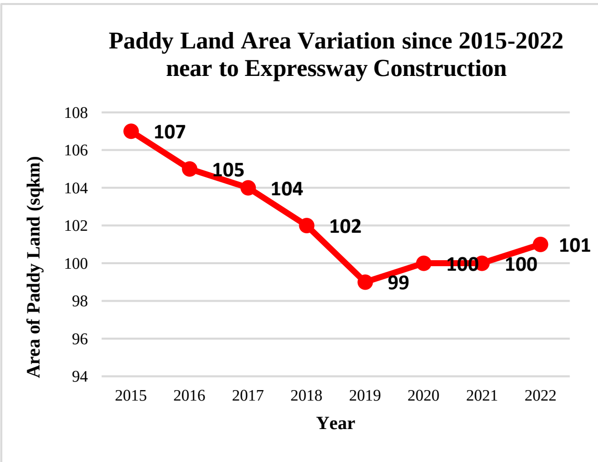

Figure 3.2: Paddy land area variation since 2015-2022 near to expressway

From Figure 3.1, it is evident that there was no observed reduction in the paddy land area due to the construction of the expressway in 2015 within the Hambantota district. The data was initially collected at five-year intervals, but from 2015 to 2022, the data collection frequency was increased to an annual basis. The paddy land area considered for analysis is specifically within the buffer zone adjacent to the expressway in the Hambantota district. As a result of this increased data collection, the following results were obtained.

In 2015, the paddy land area within the buffer zone measured 107 km^2. Subsequently, there was a gradual decrease in the following years. In 2016, the area decreased to 105 km^2, and in 2017, it further reduced to 104 km^2. This downward trend continued in 2018, with the paddy land area shrinking to 102 km^2. The decline persisted in 2019, with the paddy land area reaching 99 km^2, indicating a substantial reduction compared to the previous years. However, in 2020, there was a slight increase as the paddy land area expanded to 100 km^2. This value remained constant in 2021, maintaining the same level of paddy land area as the previous year. By 2022, there was a modest increase in the paddy land area within the buffer zone, with it measuring 101 km^2. This marks a slight recovery compared to the preceding years.

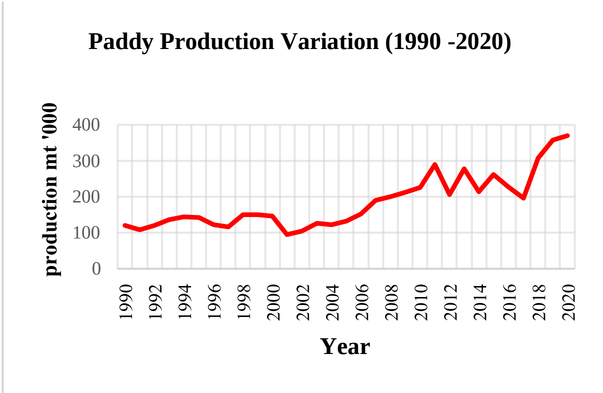

Figure 3.3: Paddy production variation since 1990-2020 in Hambantota district

Figure 3.3 represents the paddy production in metric tons within the Hambantota district over a span of 31 years, from 1990 to 2020. The paddy production in the district showed some fluctuations during this period. In 1990, production was recorded at 120.5 metric tons, which decreased slightly to 109.1 metric tons in 1991. However, it rebounded in 1992 to reach 119.6 metric tons. There was a notable increase in paddy production from 1993 to 1995, with values of 136.2 metric tons, 143.7 metric tons, and 142 metric tons, respectively. This upward trend was followed by a decrease in 1996, where production dropped to 122.1 metric tons, and further declined to 115.8 metric tons in 1997. From 1998 to 1999, there was a relatively stable period with paddy production recorded at 150 metric tons and 149.4 metric tons, respectively. In 2000, it decreased slightly to 146 metric tons, followed by a significant drop to 95 metric tons in 2001. The paddy production started to recover in the subsequent years. It increased to 104 metric tons in 2002 and further rose to 125.6 metric tons in 2003. In 2004, there was a slight decline to 123.2 metric tons, but it rebounded to 132.9 metric tons in 2005.

The period from 2006 to 2011 witnessed a substantial increase in paddy production. It reached 152.1 metric tons in 2006 and steadily climbed to 290.4 metric tons in 2011, marking a significant surge. However, in 2012, there was a sharp decline to 206.8 metric tons, followed by a recovery to 278.1 metric tons in 2013. The paddy production fluctuated in the subsequent years, with values of 213.8 metric tons in 2014, 262.9 metric tons in 2015, and 229 metric tons in 2016. In 2017, production decreased to 210 metric tons, followed by a slight decline to 208 metric tons in 2018. However, there was a notable increase to 257 metric tons in 2019, and a further surge to 292 metric tons in 2020.

Table 3.1: Correlation coefficient from years 2015 to 2022

Year	Correlation Coefficient
2015	0.8540
2016	0.9700
2017	0.9633
2018	0.8811
2019	0.8865
2020	0.8756
2021	0.8235
2022	0.9152

The paddy land area was observed in relation to the distance from the expressway for each year from 2015 to 2022. The analysis considered the paddy area on both sides of the expressway. Additionally, the correlation coefficient was calculated based on the observed results (Table 3.1). The correlation coefficients for the given years range from 0.8235 to 0.9700. Accordingly, the correlation coefficient of 1 indicates a perfect positive correlation, which means that as the distance (from the expressway) increases, the paddy land area also increases.

IV.DISCUSSION AND CONCLUSION

Between 1990 and 2020, the area of paddy land shows minimal fluctuations. The variations in paddy lands can be influenced by factors such as climatic conditions, agricultural practices, and market demands, and human and natural interventions. The changes are generally small, with only a difference of a few km^2 between consecutive years. This indicates a consistent level of paddy cultivation in the Hambantota district during this time span.

The observed decrease in the paddy land area within the buffer zone adjacent to the expressway during 2015–2022 can be attributed to various factors. These factors may include changes in land use patterns, agricultural practices, and, most significantly, development activities in the region, such as the construction of the expressway. It is worth noting that paddy production in the Hambantota district can be influenced by a multitude of factors, including weather patterns, availability of water resources, pest and disease management, technological advancements, socio-economic factors, market demand, and agricultural management practices.

The correlation coefficient analysis conducted on the relationship between the distance from the expressway and the paddy land area within the buffer zone indicates that there is a positive correlation. This means that as the distance from the expressway increases, the paddy land area also increases on both sides of the expressway. This finding aligns with the expected outcome, as areas closer to the expressway are more likely to experience negative impacts on paddy land due to various construction activities. These activities may include the establishment of supply road access, the construction of workshops, and the creation of residential areas for workers. Such activities can lead to the destruction or conversion of paddy land, resulting in a decrease in the available paddy land area.

Remote sensing methods play a crucial role in conducting long-term data analysis. While field methods are an alternative, they tend to be more expensive, require more manpower, and consume significant time. Consequently, when examining the reduction of paddy land caused by expressway construction between 1990 and 2022, remote sensing methods prove to be a more efficient approach. Through this analysis, the following conclusions can be drawn.

- Between 1990 and 2020, the area of paddy land exhibits minimal fluctuations, with data collected at five-year intervals.
- The analysis specifically focuses on the paddy land area within the buffer zone adjacent to the expressway in the Hambantota district between 2015 and 2022, with a particular emphasis on the observed decrease in the paddy land area. The data for this analysis was collected annually.
- As the distance from the expressway increases, the paddy land area also increases on both sides of the expressway.

V. ACKNOWLEDGMENT

I express my sincere thanks to the USGS Earth explore for supplying Landsat imagery for the study area of the Hambantota district. And also thank to Department of Census and statistics for provide data.

REFERENCES

Abd, H. A. A. and Al Najjar, H. A. (2013) ‘Maximum likelihood for land-use / land-cover mapping and change detection using Landsat satellite images: A case study “South of Johor”, international journal of computer & electronics research, 03(6), pp. 26–33.

Canada.ca (2015) 'Pre-processing'. Available at: https://www.nrcan.gc.ca/maps-tools-and-publications/satellite-imagery-and-air-photos/tutorial-fundamentals-remote-sensing/image-interpretation-analysis/pre-processing/9403.

Glen, S. (2021) 'Correlation Coefficient: Simple Definition, Formula, Easy Calculation Steps' (2021). Available at: https://www.statisticshowto.com/probability-and-statistics/correlation-coefficient-formula.

Kusuma, S. and Pradesh, A. (2016a) ‘Study of land use changes and urban expansion of Vijayawada study of land use changes and urban expansion of Vijayawada city using’, (February).

Kusuma, S. and Pradesh, A. (2016b) ‘study of land use changes and urban expansion of Vijayawada study of land use changes and urban expansion of Vijayawada city using’, (March 2015).

Landsat Missions (2021) 'Landsat Collection 2 Level-2 Science Products'. Available at: https://www.usgs.gov/core-science-systems/nli/landsat/landsat-collection-2-level-2- science-products.

National STD/AIDS Control Programmer (2021) 'Hambantota District Information'. Available at: https://www.aidscontrol.gov.lk/index.php?Option=com_content &view=article&id=32&Ite mid=169&lang=en.

Profile, S. E. E. (2019) ‘cultivation of fruits as alternative crops in Hambantota district: potential and prospects DP Kumarage and KKIU Arunakumara * Department of Crop Science, Faculty of Agriculture, University of Ruhuna, Mapalana ’, (April).

Rajapaksa, R. D. D. P. and Karunagoda, K. S. (2009) ‘Factor demand for paddy cultivation in Sri Lanka with special reference to fertilizer subsidy programme’, Sri Lanka Journal of Agrarian Studies, 13(2), pp. 25–38.

Song, J., Ye, J., Zhu, E., Deng, J., and Wang, K. (2016) ‘Analyzing the impact of highways associated with farmland loss under rapid urbanization’, ISPRS International Journal of Geo-Information, 5(6).

Utami, N. P. and Ahamed, T. (2018) ‘Spatial analysis to determine paddy field changes in Indonesia : A case study in suburban areas of Jakarta spatial analysis to determine paddy field changes in Indonesia: A case study in suburban areas of Jakarta’.