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Climate Change Induced Flood Inundation Mapping of Ala River Catchment in Akure, Ondo State, Nigeria

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Abstract

Flood is a common natural disaster experienced around the globe due to the overflow of water on dry land that are caused by different factors. This paper develops flood inundation maps for Ala River catchment arising as a result of changes in the climate system. The aim was achieved by simulating a hydraulic model, with peak discharges resulting from a hydrologic simulation of the effect of projected climate changes on the stream-flow as its main input. Geographic Information System (GIS) and HEC-RAS combined with HEC-GeoRAS extension were used as modeling tools. The hydrologic simulation was done taking into consideration the Representative Concentration Pathway (RCP) 4.5 and 8.5 climate scenario, and these scenarios in turn affects the output of the hydraulic simulation for the flood inundation mapping. With this, the River Ala catchment was successfully modeled and its flood inundation maps for different years: 2020, 2025, 2030, 2045, 2070 and 2100 were developed. The maximum flood inundation of Ala River catchment which will occur in the year 2100 under the RCP 8.5 and RCP 4.5 climate scenario was simulated to be 2.50 km^2 and 1.90 km^2 respectively. These results suggests that the Ala river catchment is susceptible to high flooding in the future and water resources managers can adopt this results in implementing policies and strategies to tackle this projected climate impact on the river stream-flow.

Keywords: Ala River, representative concentration pathway, climate scenario, flood inundation, mapping.

1.0 Introduction

Flood is a temporary overflow of water onto land that is normally dry. It is a common natural disaster around the globe, and failure to evacuate flooded areas can lead to death and injuries. These hazards and losses accompanying flooding can be prevented and/or reduced by providing flood inundation maps which is capable of providing necessary information about the extent and characteristics of flood which can occur in that area (Vahdettin and Ozgur, 2016).

According to Teh and Khan (2021), in the last twenty first century, floods affected more people than any other type of disaster with the social impacts estimated as 1.3 million people lost their lives and 4.4 billion people were displaced. Ide *et al.* (2021) investigated flood-related political unrest between 2015 and 2018 in Africa, Asia, and the Middle East. Their findings show that flood-related political unrest occurs within two months after 24 % of the 92 large flooding events were recorded in the study areas.

Today, floods are increasing in frequency and intensity, and the frequency and intensity of extreme precipitation which gives rise to flood is expected to continue to increase due to climate change. Flood inundation models are required to understand, assess and predict flood events and their impact in any area of concern. According to Teng (2017), recent years have shown systematic improvement in the capability of flood inundation modelling and mapping. The results from hydraulic models can be used in flood risk mapping, flood damage assessment, real time flood forecasting, flood related engineering, water resource planning, investigating flood plain erosion and sediment transport, floodplain ecology and river system hydrology (Teng, 2017).

The flood occurrence of Ala River has been discovered as being disastrous as the river flow cuts across some part of the semi-urban and urban areas of Akure city (Ibitoye *et* al., 2019; Olalekan and Fadesola, 2017). This can be attributed to a relative increase in the amount of rainfall which arises as a result of the climate change experienced round the world as well as sediment deposit on rivers channel. Flooding along the Ala River in Akure metropolis is an annual occurrence. The unsafe condition of lives and properties along the river has over the years become an issue of serious concern to individuals, local, state and federal government. Properties worth billions of Naira are damaged yearly. Rainy season is usually worse for the people living close to Ala river in Akure as residential buildings and business premises are submerged making life unbearable for the residents of these areas and patrons of business located there (Olajire *et al*., 2018).

HEC-RAS is a tool developed for analyzing hydraulics of river system by U.S. Army Corps of Engineering´s Hydrologic Engineering Center. The main input in HEC-RAS for performing hydraulic analysis are geometric data and flow data (USACE, 2009). Basic geometric data consists of physical feature of river i.e. channel length, banks, flood banks and cross-sections of the river while additional geometric data defining bridge and culverts, levee alignment, blocked structures, inline structures and storage area can also be incorporated in the software (Brunner, 2016). Several researchers have successfully applied this tool to model flood events in many region of the world such as India (Kumar *et al.*, 2020; Patel *et al*., 2017; Rangari *et al.*, 2019), Romania (Stoleriu, 2020; Huţanu, 2020), Tunisia (Khalfallah and Saidi, 2018), Turkey (Ogras and Onen, 2020), Malaysia (Romali, *et al*., 2018), Korea (Dasallas et al., 2019).

Review of literature reveals that not much work has been done on the impact of climate change on the flood inundation of Ala River in Akure, Ondo State which is the only drainage river of the town. Hence, the objective of this study is to simulate a hydraulic model for the River Ala using HEC-RAS and generate flood inundation maps for future years for the river catchment. Having considered the impact of climate change on the stream-flow of Ala River (Akinwumi *et al*., 2020), it will further contribute to flood study in the catchment area by carrying out studies on the flood inundation of the river catchment. This paper is therefore structured to provide necessary information on the extent to which the river Ala will be inundated by flood.

2.0 Materials and Methods

2.1 Description of the Study Area

Akure, where the studied river is sited is the capital city of Ondo State, in the south-western part of Nigeria. It is located between latitude 7°15’N and 7°28’N of the equator and longitude 5° 6’E and 5°21’E of the Greenwich meridian, the total land area is approximately 41.2 km^2. Ala river basin lies within the Akure metropolis. Ala river basin extent is between 5°9’E, 7°17’N and 5°17’E, 7°16’N. Ala river transverse between Akure South and Akure North Local Government Area. River Ala and its tributaries are one of the main tributaries of River Ogbese, Southwestern, Nigeria. The River has a total length of about 57 km with about 14.8 km within Akure Township (Figure 1). It took its source from northwestern part of Akure town and flow towards Southeastern part of the town. Akure Township dominates the upstream of River Ala while rural towns such as Ilado, Ehinala, Ajegunle, Owode, Aiyetoro and Araromi are located in the downstream where the water is being used for drinking water and other domestic purposes (Ayeni *et al.,* 2011).

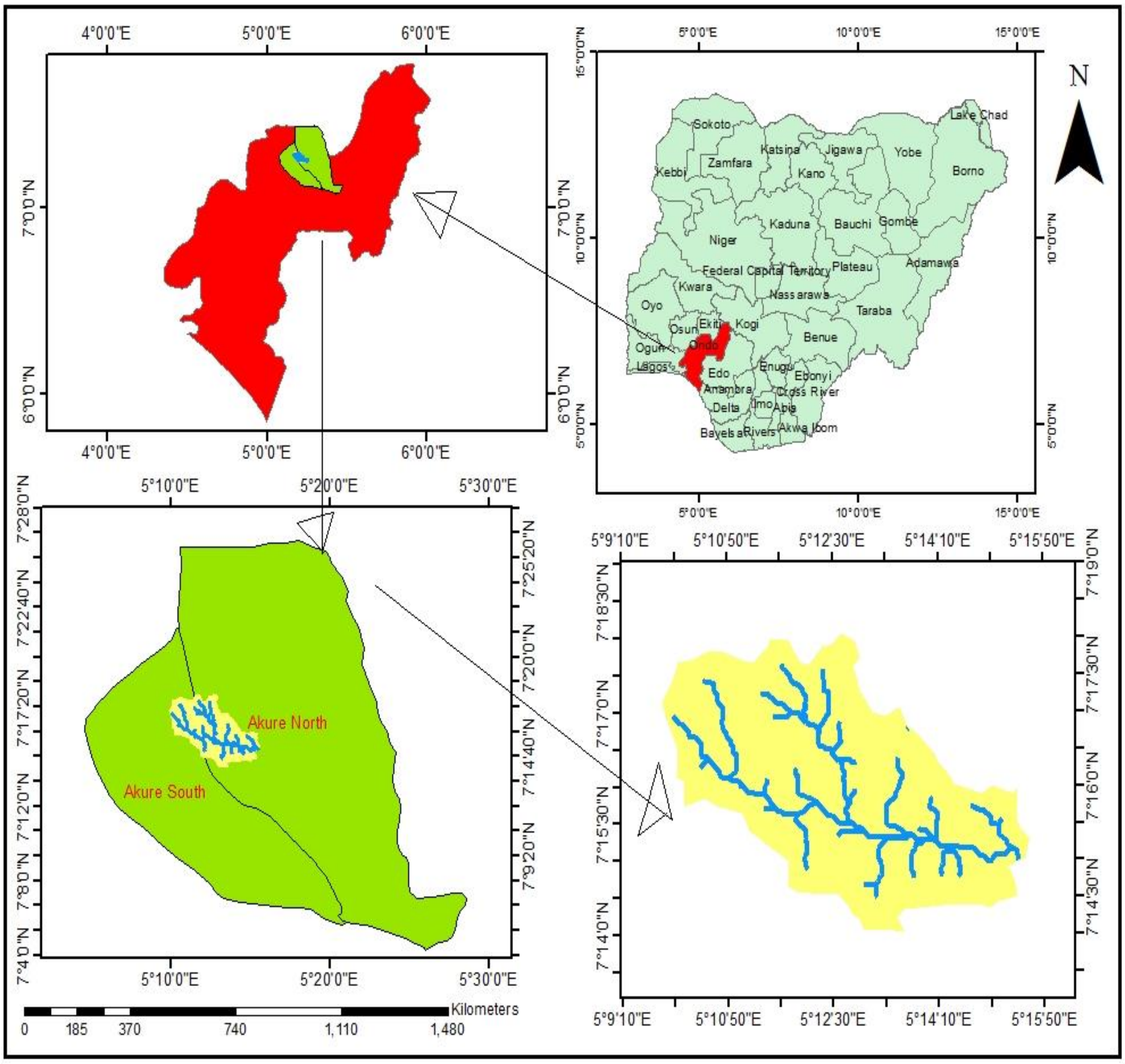

Figure 1: Map of the study Area (River Ala)

2.2 Data for Hydraulic Modelling: HEC-RAS

Data required for Hydraulic modeling (HEC-RAS) are:

i. Triangulated Irregular Network (TIN)
ii. Manning’s value
iii. Projected Peak discharges (Hydrology) for different climate scenarios

Triangulated Irregular Network (TIN)

Digital Terrain Model in the form of Triangulated Irregular Network (TIN) is required for the hydraulic analysis of river system. TIN must be of high-resolution with continuous surface and it represent the bottom of the river and adjacent flood plains. TIN for the study areas was derived by converting the DEM in ARCGIS and combining with cross-sectional data taken on site.

Manning’s Value

The Manning’s value for different land use types is given in Table 1 according to (Chow *et al*., 1988).

Table 1: Manning’s n values

Land Use	Manning’s coefficient
Cropland	0.05
Pasture	0.05
Barren Land	0.04
Water bodies	0.035
Forest	0.1
Developed areas	0.12

Projected Peak Discharges (Hydrology)

Once the geometry is completed, the projected peak discharges for the different climate scenarios is entered into the model. HEC-RAS requires flows to be entered at all upstream boundaries. Flows were provided to the model for the years: 2020, 2025, 2030, 2045, 2070, and 20100. The peak flows used for this study and simulation is obtained from Akinwumi *et al.* (2020).

2.2.1 Hydraulic Model Development

Hydraulic analysis of the river system was performed with the help of HEC-RAS along with HEC-GeoRAS in ARCGIS. Schematic diagram of the modelling approach for performing hydraulic analysis is as shown in Figure 2.

The methodology used for performing hydraulic analysis can be divided into three parts, which are:

i. Pre-processing: Developing geometry of river in ARCGIS;
ii. Processing: Performing hydraulic computation in HEC-RAS ;
iii. Post-processing: Processing RAS results in ARCGIS.

HEC-RAS software was downloaded from: http://www.hec.usace.army.mil/software/hec-ras/downloads.aspx

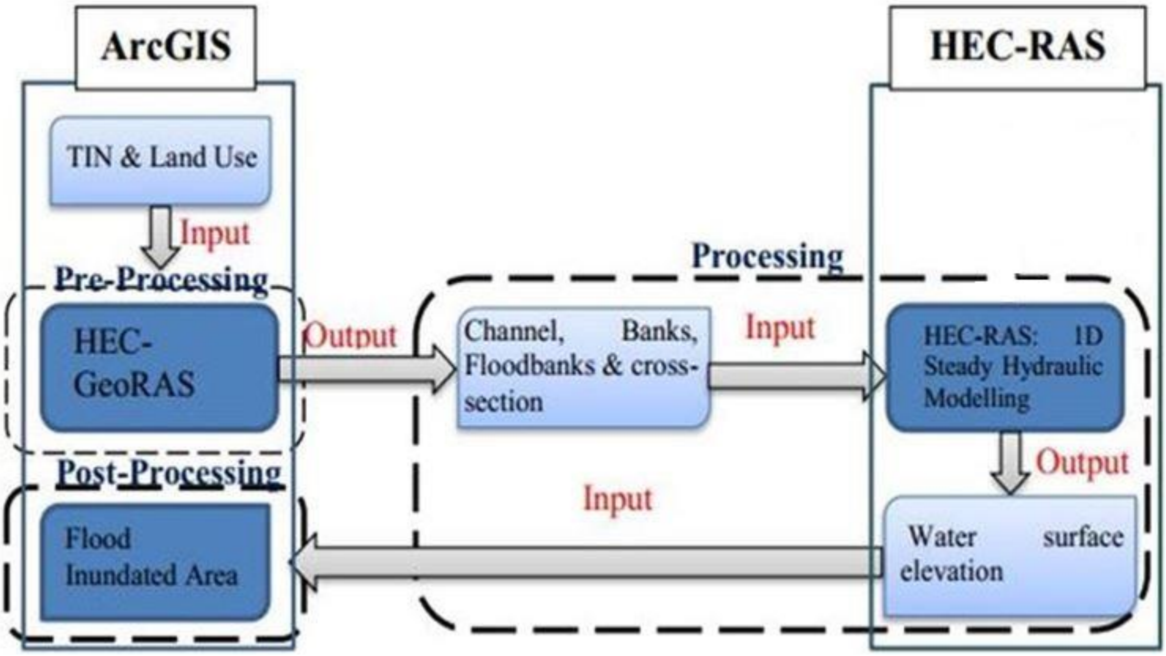

Figure 2: Hydraulic Modeling Approach

2.2.1.1 Pre-Processing

This is the development of the river geometry in ARCGIS. Firstly, TIN was generated based on the DEM of the study area. The DEM was refined using pre-processing tools (DEM reconditioning and fill sink) available in HEC-GeoHMS. Based on the generated TIN of the study area, geometric layers like stream centreline, bank lines, flow path centrelines and cross section cut lines were created. These layers represented the actual river system. The river cross-sectional cut lines were generated in HEC-GeoRAS at a regular interval which were further refined manually based on their necessity. All the layers generated their attributes like name, length, topology, elevation, positioning for them to be identified while importing them to HEC-RAS.

2.2.1.2 Processing

This is the performance of hydraulic computation in HEC-RAS. All the geometric data were imported into HEC-RAS and the verification of quality of data was done. To run the flood analysis, 1D Steady flow simulation was carried out under subcritical flow regime. The peak discharges for each projected effect of climate change on the river flow were input for the analysis. These discharges values along with suitable boundary conditions were used as input for steady flow data. Since the selected flow regime was subcritical, therefore, boundary condition was defined only at the downstream end of the river and it was defined by the critical depth. The boundary conditions at the junction were predefined by the software. The output of the simulation was water level for all the flood values. The water level can be viewed in cross-sections or longitudinal section of the river. Water surfaces for each projected year's flood and river centreline were exported back to ArcGIS. The file exported from HEC-RAS to ArcGIS was in Spatial Data Format (SDF).

2.2.1.3 Post-Processing

This is the processing of the output from HEC-RAS in ARCGIS. Firstly, the file exported from HEC-RAS in SDF was first converted to XML which is readable by ARCGIS. In this step, mapping of flood inundated area was carried out. Before processing the outputs from HEC-RAS, a new set of layers were created and terrain model (TIN) generated in pre-processing step was specified for performing the floodplain delineation. The rasterization cell size for output DEM was also specified in this step. Then, the outputs from HEC-RAS previously converted to XML format was imported into ArcGIS. While doing so stream centrelines, cross-section cut lines, bank points, and bounding polygon were created in ArcMap. The software creates different bounding polygons, the spatial limit for floods, based on the water surface elevation at cross-section cut lines for different year floods. Finally, inundation mapping was carried out in two steps: Water surface generation and floodplain delineation using raster. In water surface generation, TINs for water surface for different year floods were created from the altitude of water surface in each of the cross-sections. Floodplain delineation was carried out using water surface that TINs generated in previous step and terrain model TIN. Thus, floodplain boundaries and their depths were calculated. The flood inundation areas for different flood values were represented by polygons while their respective depths were represented by DEM (raster format). In this research, rasterization cell size was set as 20 map units for the study area.

3.0 Results and Discussions

3.1 Flood Inundation Mapping

The output from the HEC-RAS was imported into ARCGIS so as to show the areas inundated and the outcomes are presented in Figure 3 to 15. The flood geometry of the Ala River catchment was drawn in ARCGIS and then overlaid on the Land use map of the watershed in other to determine the inundation area.

The flood inundation maps for the RCP 4.5 climate scenario for the year 2020, 2025, 2030, 2045, 2070 and 20100 are shown in Figure 3 to Figure 8. Similarly, the flood inundation maps for the RCP 8.5 climate scenario for the same years are shown in Figure 9 to Figure 14 respectively. Also, the inundated area for each projected year due to RCP 4.5 and RCP 8.5 climate change scenario and the percentage increase in the inundated area (using 2020 as baseline year) is presented in Table 2.

From Table 2, the result obtained for RCP 4.5 climate change scenario shows that the inundated area increase by 100 % in year 2070 while the value obtained for RCP 8.5 for this same year was about 34 %. Although, RCP 4.0 gave moderate lower inundated areas than that of RCP 8.5 for all years, the percentage increase is higher. The highest inundated areas of 2.5 km^2 was obtained in year 20100 while RCP 4.5 gave a value of 1.90 km^2 for the same year.

The hypothetical carbon-concentration scenario RCP 8.5 adopted in this study represents the worst but not necessary the most realistic scenario (Hsiao *et al.*, 2021). In this study, the assumption that the climate, land-use, and infrastructure conditions will remain unchanged in future may result in over or under estimations of flood inundated areas. Higher land inundation under RCP 8.5 emissions where 6.06 % of land is projected to be flooded by 20100 is unlikely as this scenarios overestimates carbon dioxide emissions. Under RCP 4.5 emissions scenario, 4.6% is projected to be inundated by 20100. Emissions under this scenario is the most probable baseline scenario.

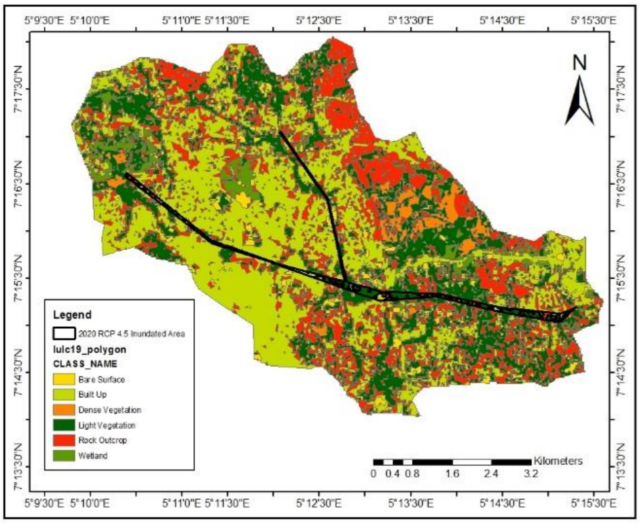

Figure 3: I Inundation of Ala River Catchment for year 2020 RCP 4.5 Climate Scenario

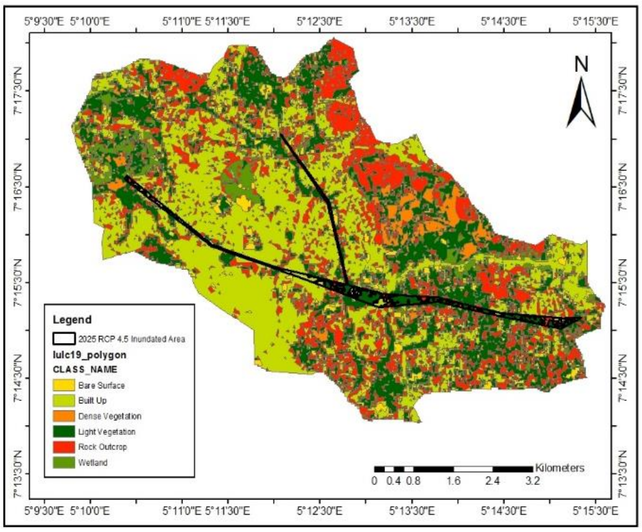

Figure 4: Inundation map of Ala River Catchment for year 2025 RCP 4.5 Climate Scenario

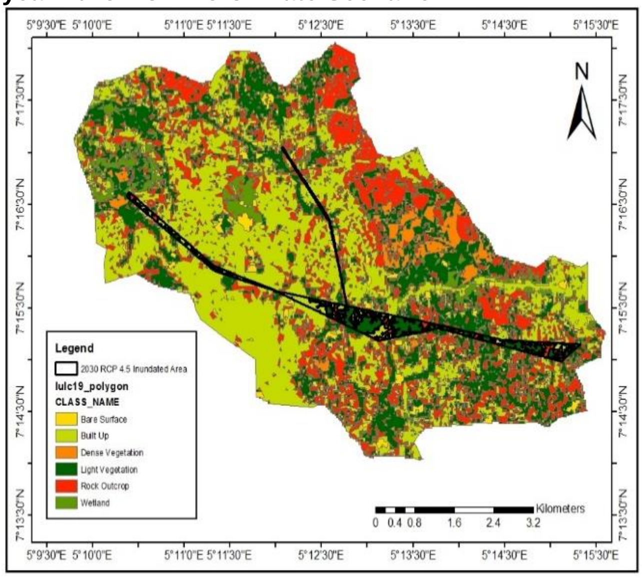

Figure 5: Inundation map of Ala River Catchment for year 2030 RCP 4.5 Climate Scenario

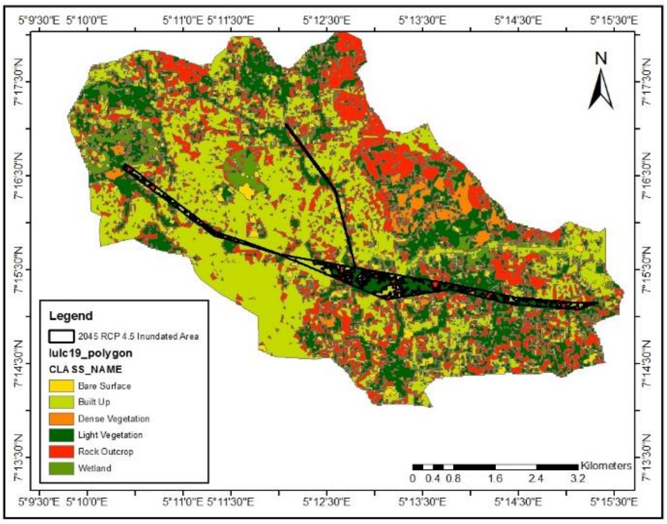

Figure 6: Inundated Area of Ala River Catchment for year 2045 RCP 4.5 Climate Scenario

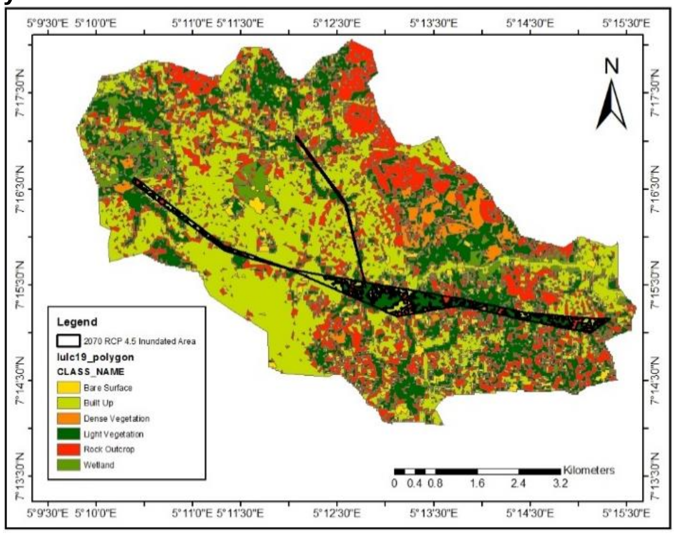

Figure 7: Inundation map of Ala River Catchment for year 2070 RCP 4.5 Climate Scenario

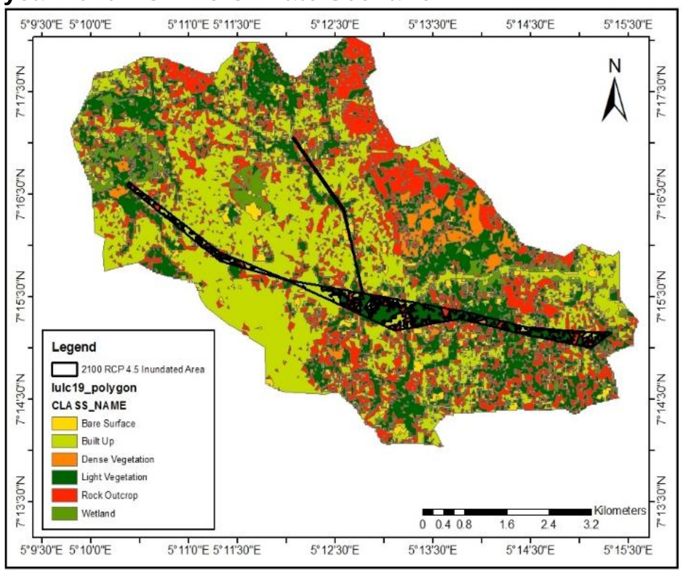

Figure 8: Inundation map of Ala River Catchment for year 2100 RCP 4.5 Climate Scenario

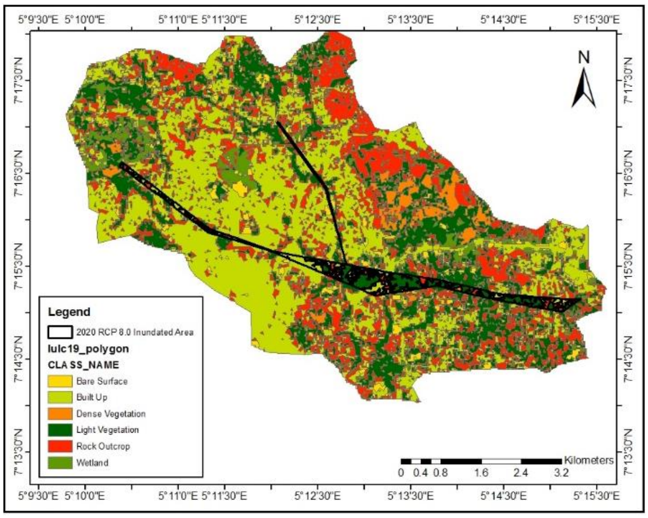

Figure 9: Inundation map of Ala River Catchment for year 2020 RCP 8.5 Climate Scenario

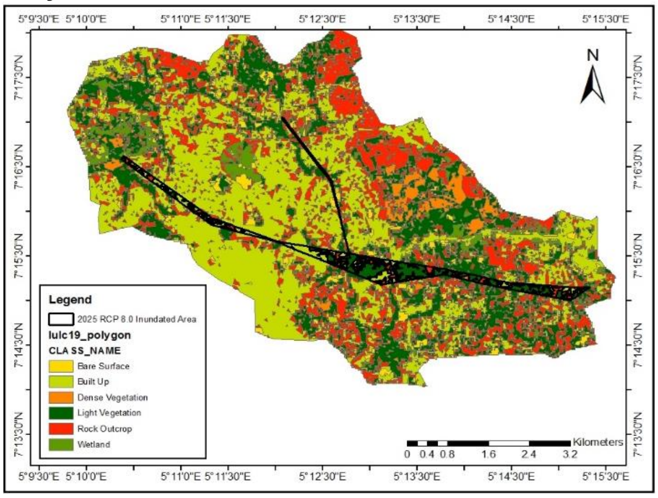

Figure 10: Inundation map of Ala River Catchment for year 2025 RCP 8.5 Climate Scenario

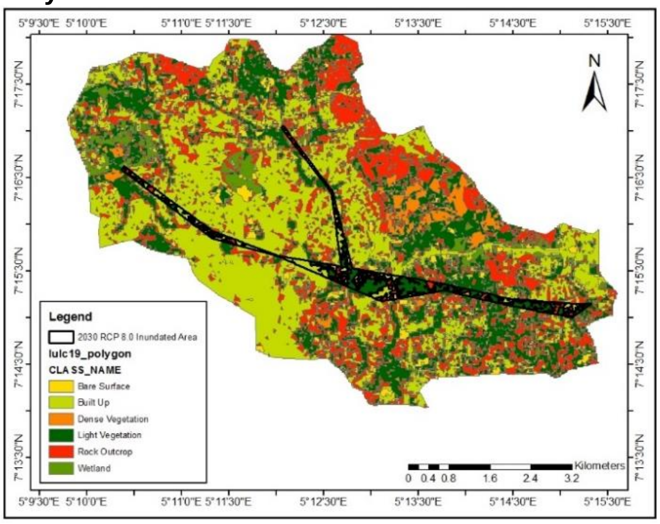

Figure 11: Inundation map of Ala River Catchment for year 2030 RCP 8.5 Climate Scenario

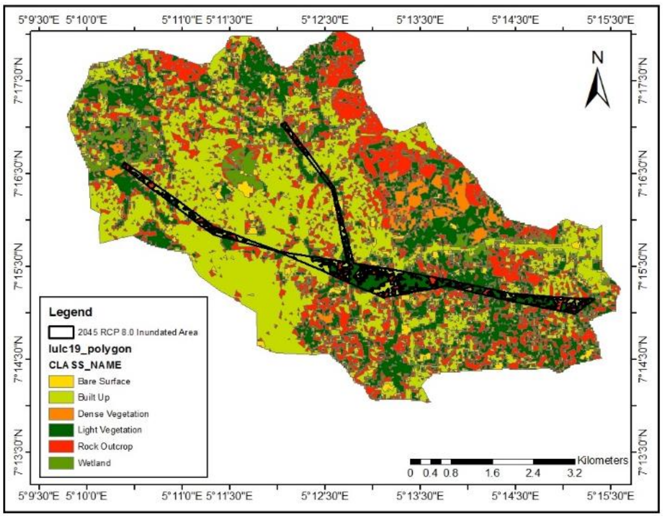

Figure 12: Inundation map of Ala River Catchment for year 2045 RCP 8.5 Climate Scenario

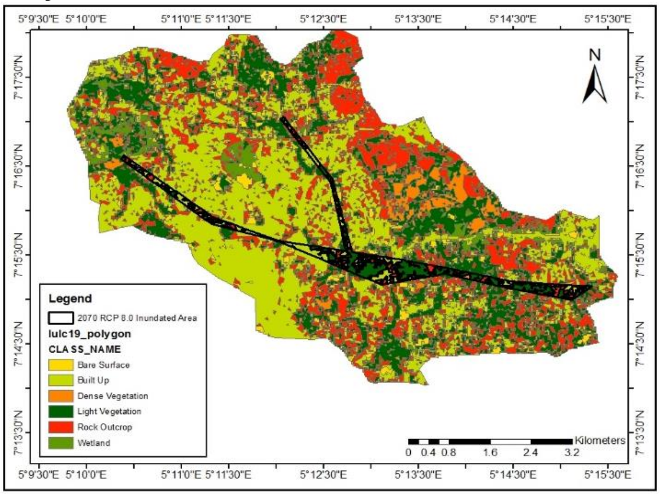

Figure 13: Inundation map of Ala River Catchment for year 2070 RCP 8.5 Climate Scenario

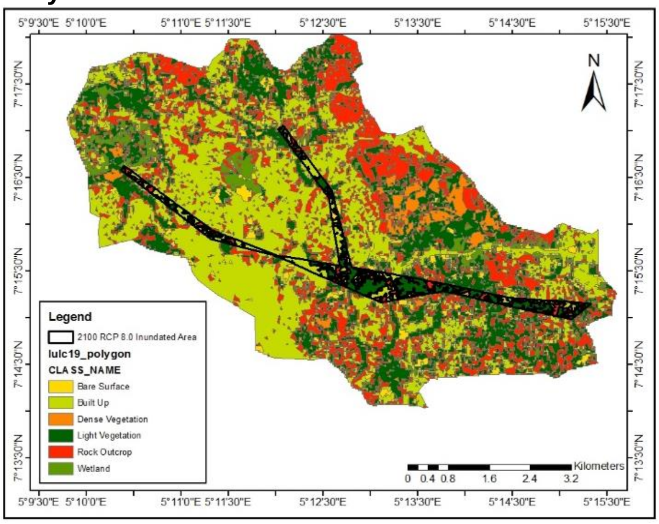

Figure 14: Inundation map of Ala River Catchment for year 2100 RCP 8.5 Climate Scenario

Table 2: Summary of the Area Inundated for RCP 4.5 and RCP 8.5 Climate Change Scenarios

Year	Area Inundated			
	RCP 4.5 (km^2)	% increase	RCP 8.5 (km^2)	% increase
2020	0.89	Base line	1.68	Baseline
2025	1.09	22.5	1.79	6.5
2030	1.37	53.9	2.05	22.0
2045	1.58	77.5	2.16	28.6
2070	1.79	101.1	2.25	33.9
20100	1.90	113.4	2.50	48.8

4.0 Conclusion

In this study, the flood inundation mapping of Ala River was conducted using HEC-RAS with HEC-GeoRAS in ARCGIS environment. Inundation maps was obtained for the years 2020, 2025, 2030, 2045, 2070, and 2100 under climate scenarios RCP 4.5 and RCP 8.5**.** Upon considering the impact of climate change on the stream-flow of Ala River, the areas to be affected by flooding were determined. These maps are very important in the economic planning and implementation of policies and strategies necessary for effective structural and non-structural measures for flood mitigation and reduction. The maximum flood inundation area of the Ala river catchment which will occur in the year 2100 under the RCP 8.5 and RCP 4.5 climate scenario was simulated to be 2.50 km^2 and 1.90 km^2 respectively.

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