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Spatial and Seasonal Patterns of Flood Inundation in Lokoja, Kogi State, Nigeria

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Abstract

The study examines spatial patterns of flood inundation in Lokoja, Kogi State, Nigeria. The Maximum Likelihood Classifier algorithm of the supervised land use/cover classification technique was utilized. The results obtained from the analysis were used to estimate the magnitude and visualize the seasonal and spatial pattern of flood inundation events. Eight Landsat images comprising two sets for each year (dry and wet seasons) were acquired from the United States Geological Survey (2018). The Landsat images were classified into land cover classes such as built-up, vegetation, and water body. After completing the land cover classification, the area of each class was determined and converted to square kilometers and percentages for both wet and dry seasons. Based on the classification, the brown colour depicts the built-up areas, blue for water body, and green for vegetation. Finally, accuracy assessment was carried out using historical Google Earth images, informed knowledge of the area, and GPS coordinates. ArcMap 10.5 was used to produce land use/cover maps for the study period. Overall, the result revealed the effect of flood inundation to be more intense on vegetation. 1.62%, 4.60%, 23.05% and 6.43% of vegetated land was lost in 1999, 2009, 2012 and 2018, respectively. Therefore, efforts to improve resilience against variable weather, flood inundation, and seasonal uncertainties should be encouraged.

Keywords: Inundation, Flood, Spatial and seasonal, Lokoja.

1. Introduction

1.1. Problem Statement

Flood, a major natural disaster, poses a great risk to humans, agriculture, housing and infrastructures (Chang et al., 2008). According to a well-documented report by Doocy et al. (2013), flood events account for over 50% of the mortality and about 33% of the economic losses associated with natural disasters worldwide. However, the rate of exposure to flood risks continues to increase with the growth of cities (Milly et al., 2002). One significant effect of flood in riverine areas is inundation, which occurs when major rivers and tributaries rise above their banks (Kadam and Sen, 2012). Over the past decade, inundation has led to more than 20,000 annual fatalities and negatively affected about 75 million people globally (Sarhadi et al., 2012). In most cases, this event is intensified by the changes in land use features due to frenetic urban spread (Alexander et al., 2006, Brath et al., 2006, Ntegeka and Willems, 2008; Oudin et al., 2008).

Flood is the most frequently occurring and widespread natural disaster in Nigeria (FGN, 2013). Common causes of flooding in Nigeria include dam failures, prolonged rainfall, drainage blockages (Jeb and Aggarwal, 2008), urban growth (Adeniran et al., 2020; Otokiti et al., 2019), and flood plain encroachment (Salami and Otokiti, 2019). The 2012 flooding in Nigeria is regarded as the most devastating flood event, where Kogi State was severly affected due to its location at the confluence of the nation's major rivers (River Benue and Niger). Specifically, the findings of Aderoju et al. (2014) on the assessment of 2012 flood event revealed that 73 communities in 7 Local Government Areas, including Lokoja were inundated, and about 345,273 people were displaced. Furthermore, Buba et al. (2021) study indicated that about 70% of the total land area (6,258 Ha) in Lokoja is highly susceptible to flood inundation.

The future prediction of the exacerbated impact of climate change and extreme weather events will increase the severity and frequency of the inundation phenomenon (Igobwa et al., 2022). Hence, providing information (usually in the form of maps) to help communities understand flood inundation is vital to making cost-effective mitigation decisions, developing a timely response, and assessing the damage (Refice, 2018).

The capability of earth observation data and Geographic Information Systems (GIS) to derive meaningful flood information has been demonstrated in many studies (Adeyeri et al., 2017; Adeniran and Otokiti, 2019; Otokiti et al., 2019; Lee et al., 2012; Stefanidis and Stathis, 2013; Pradhan, 2010; Abdelkarim et al., 2019). Hence, integrating geospatial methods into flood risk management is widely recognized as one potent means for addressing flood challenges. While significant efforts have been made in flood risk mapping in Nigeria, only few studies on spatial and seasonal patterns of flood inundation exist. Consequently, the need for this study is apparent as it evaluates the magnitude, spatial and seasonal patterns of flood inundation in Lokoja, Kogi State, Nigeria, using satellite imagery such as Landsat. This is also significant to physical planning in terms of facilities and infrastructural development within the area.

1.2. Literature Review

Floods are described as water covering land areas often not covered by water (European Union, 2007). According to Watson and Adams (2010), flooding arrives with unanticipated, unexpected, and unwelcome intensity, thereby posing a huge risk to the life and property of people in its path and the economy and environment. Notably, the number of flood victims in Africa has increased dramatically over the last decades (EM-DAT, 2010). The frenetic increase in the number of people affected by flood has triggered the use of different tools that provide valuable information that can help address the increasing flood risk.

Among available tools, image classification and change detection have become a valuable component of flood risk assessment, monitoring, mitigation, and management in recent years (Piegay et al., 2015). In the form of inundation maps constitutes a viable means for developing a timely response targeted at reducing destructive effects connected to floods (Refice, 2018). Image classification and change detection techniques are used to identify differences and quantify the temporal effect using multi-temporal remote sensing data (Singh, 1989).

Information on land use/cover is commonly used for flood risk assessment (Otokiti et al., 2019; Righini and Surian, 2018). Otokiti et al. (2019) conducted a study on geospatial mapping of flood risk in Lagos, Nigeria, by combining land use information (land use and normalized difference water index) derived from a Sentinel-2 image with information derived from a digital elevation model (elevation, slope, flow accumulation, drainage density, and curvature). The central focus of their study revolves around using image classification techniques alongside other geospatial techniques to delineate areas that are vulnerable to flooding in Lagos. Similarly, Ishaya et al. (2009) combined the image classification technique with geospatial techniques like a Global positioning system, cartography, and geo-visualization to determine the flood-prone areas in Abuja, Nigeria.

Mukhtar et al. (2009) adopted image classification and change detection techniques to evaluate the effect of land use/cover dynamics on flooding in Kano Metropolis, Nigeria, between 2001 and 2012. Furthermore, they developed a flood risk scenario for the study area in 2035. The results demonstrated that image classification and change detection techniques present an opportunity to forecast flood risk scenarios and develop robust solutions to curb effects.

Abubakar et al.'s (2012) study further provides inputs to flood risk monitoring using image classification and change detection techniques. The study evaluated the impact of land use/cover dynamics along the river Kaduna flood plain (2003-2010). The results revealed remotely sensed data's capability to characterize environmental change over space and time and how it influences flooding.

For this study, the spatial and seasonal flood inundation patterns are also based on image classification and change detection techniques using Landsat images captured at different times (dry and wet seasons) on the same area. Nigeria has only two seasons. What is responsible for this is the Inter-Tropical Convergent Zone (ITCZ), being a dictator for the wet and dry season in Nigeria and generally in the tropics. With this, the sun crosses the equator twice a year (March and September) and consequently makes for the wet season, while in December and July, the sun is at the greatest extent of the north of the equator, making for the dry season.

2. Research Method

2.1. Study Area

Lokoja, the capital of Kogi State, is the first administrative capital of modern-day Nigeria and is popularly known as the confluence town because it hosts the Niger River and Benue River (two major rivers in Nigeria) (Figure 1). The town is located between 70 45'N and 70 51'N latitude and 60 41' E and 60 45' E longitude. The study area falls within the 189/054 path/row (a descending orbit of the satellite in which each is calibrated into 119 rows). It is characterized by a high slope with the ground level of the study area ranging between 35 m to 428 m above mean sea level. Agriculture is the main occupation of Lokoja residents. Our research domain is characterized by wet seasons (April – October) and dry seasons (November – March). Hence, our study considered only the satellite data between the two seasons. The relative humidity of the study domain is estimated at 60%, and annual rainfall ranges between 1,100mm and 1,300mm. The Niger River outfall travels through the eastern part of the town, leading to the flood inundation risk. Heavy rainfall intensity in the study area may trigger the river and its tributaries to spill over their banks, thus inundating the town. Flood events in 2012 and -2018 have been documented as the most devastating floods in the study area.

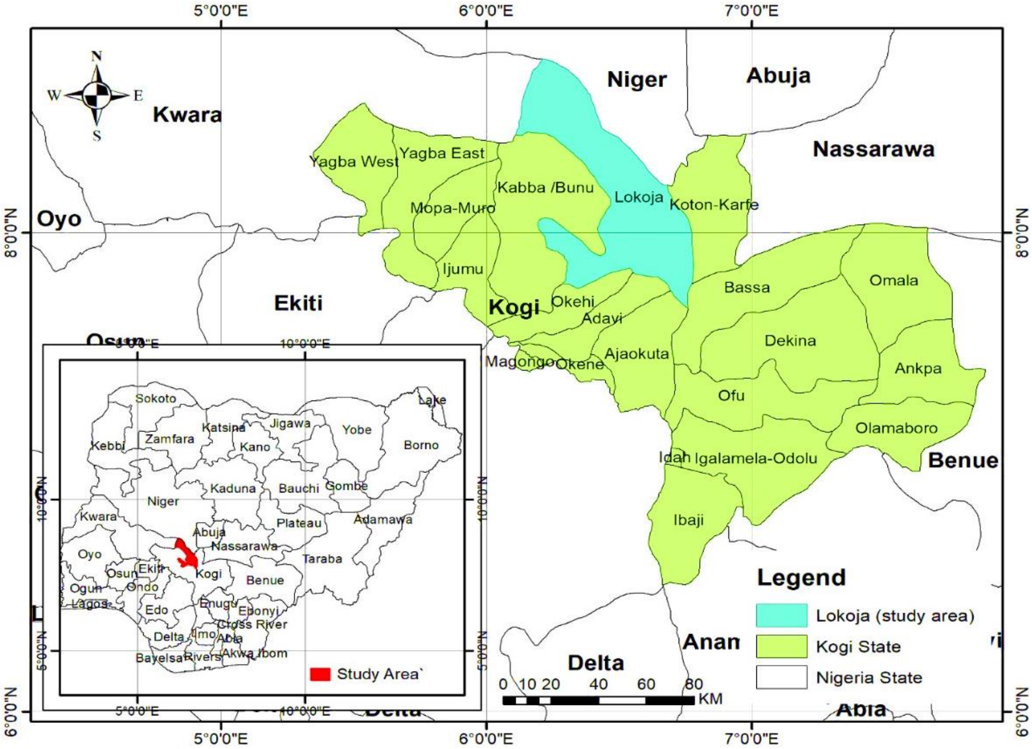

Figure 1. Study Area Map.

2.2. Data Analysis

Singh (1989) and Refice (2018) noted that the development of inundation maps is somewhat similar to land use/cover maps. Thus, using a supervised classification technique for inundation mapping is quite popular (Ireland et al., 2015; Gnecco et al., 2017). Furthermore, Solin et al. (2011) asserted that land use/cover change is critical to understanding flood events, while Bhatt et al. (2014) noted that land use/cover maps contribute significantly to flood risk management. This study analyzed seasonal flood inundation patterns trends from 1999, 2009, 2012, and 2018 in Lokoja, Kogi State, Nigeria, based on the Maximum Likelihood Classifier algorithm of the supervised land use/cover classification technique. The result obtained from the analysis is used to estimate the magnitude and visualize the seasonal and spatial pattern of flood inundation events.

Eight Landsat Images comprising two sets for each year (dry and wet seasons) were acquired from the portal of USGS (United States Geological Survey, 2018). Comprehensive information about the satellite images is presented in Table 1. The Landsat images were classified into land cover classes. Three (3) land-cover (LULC) classes were identified: built-up, vegetation, and Water Body. After completing the land cover classification, the area of each class was determined and converted to square kilometers and percentages for both wet and dry seasons. Based on the classification, the brown colour depicts the built-up areas, blue for water bodies, and green for vegetation. Finally, accuracy assessment was carried out using historical Google Earth images, informed knowledge of the area, and GPS coordinates. ArcMap 10.5 was used to produce landcover maps for the study period.

Table 1. Summary of Landsat Images Acquired for the Study.

S/No	Image Year	Path and Row	Data Set	Image Captured Date	
				Dry Season	Wet season
1	Lokoja 1999	189/55	TM	13/02/1999	16/08/1999
3	Lokoja 2009	189/55	ETM+	15/01/2009	12/09/2009
4	Lokoja 2012	189/55	ETM+	12/03/2012	02/07/2012
5	Lokoja 2018	189/55	ETM+	25/02/2018	20/08/2018

3. Results and Discussion

In 1999, vegetation was the dominant land cover feature in the study area as shown in Figure 2a, covering 72.71% (in the dry season) and 71.66% (in the wet season). Water bodies expanded from 22.13% in the dry season to 23.18% in the wet season, while built-up (5.16%) remained the same over the two seasons (Table 2). This shows that a change in the climatic condition (dry to raining season) resulted in about 1.62% of vegetated land to flood inundation. Built-up was observed not to have experienced inundation because of the distance that is relatively far from the Niger River outfall.

In 2009, as revealed in Figure 2b, Lokoja was still mainly covered by vegetation, totaling 66.3% (in the dry season) and 63.26% (in the wet season) of the land area. The spatial extent of built-up (11.5%) was uniform over the two seasons. Increase was observed in the water body with the spatial extent between 22.18% in the dry season and 25.22% in the wet seasons. By observing the result presented in Table 2, vegetation was observed to have experienced the highest impact of flood inundation in 2009, resulting in about 4.60% reduction in the proportion of vegetation.

The predominance of vegetation over the two seasons and outward spread of built-up from the central part to the northern, western, and southern part of the study area were observed in 2012 (Figure 3a). However, built-up and vegetation recorded a decrease in their respective land areas. Specifically, built-up decreased from 14.36% in the dry season to 12.89% in the wet season (10.27% decrease) while vegetation reduced from 63.53% in the dry season to 48.88% in the wet season (23.05% decrease). The difference is the case of water which witnessed an increase from 22.11% in dry the season to 38.23% in the wet season of the same year. The results indicate that 23.05% of the area covered by vegetation and 10.27% of the area covered by built-up in the dry the season were replaced by water in the wet season of 2012. Compared with previous years (1999 and 2009), flood inundation was more pronounced in 2012, with an overall growth of 72.86% between the two seasons.

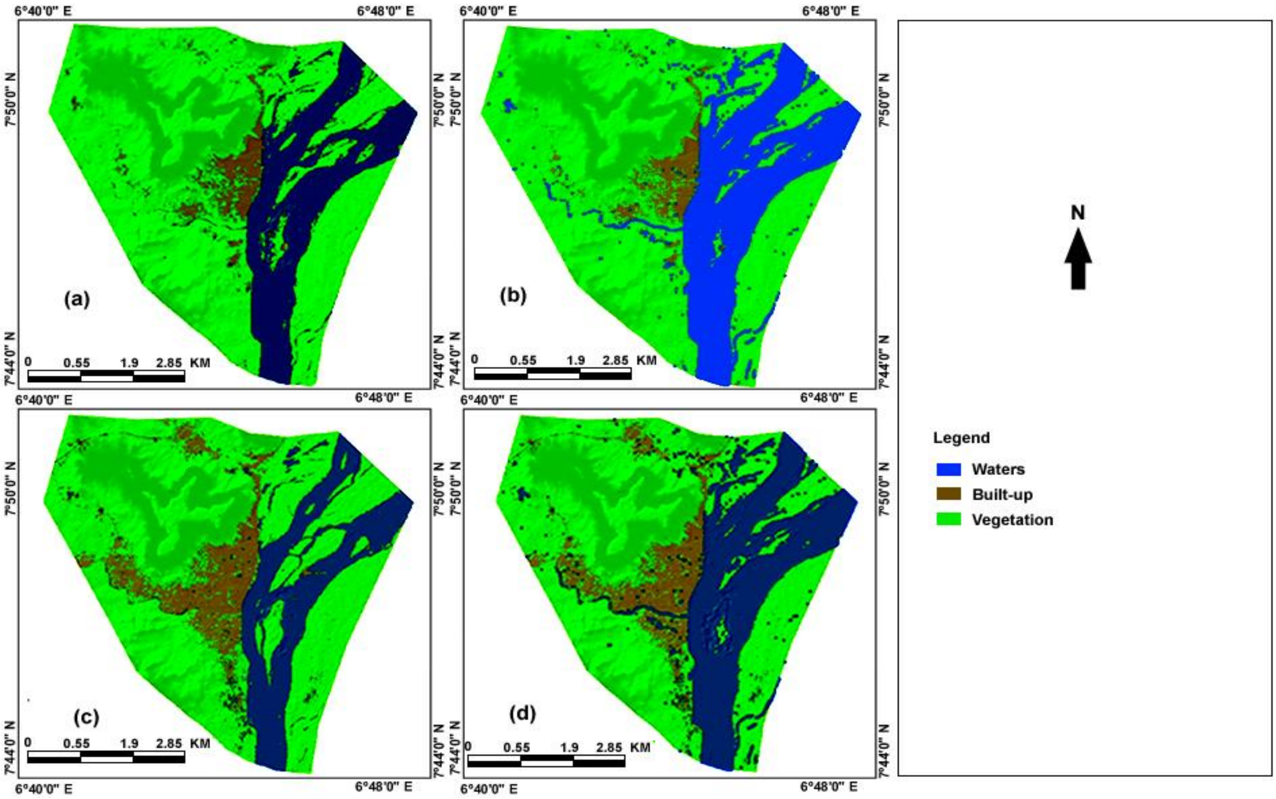

Figure 2. Composite Land Use Cover for Lokoja in 1999 and 2009. (a) 1999 dry season, (b) 1999 wet season, (c) 2009 dry season, (d) 2009 wet season.

Based on the classified images of 2018 (Figure 3b), it was revealed that about half of the study domain is mainly covered by vegetation over the two seasons. Specifically, the proportion of vegetation reduced from 58.76% in the dry season to 54.98% in the wet season reveals the study area's degree of difference. The spatial extent of built-up reduced from 18.25 to 17.22%, while water increased from 22.99 to 27.8% over the two seasons, respectively. The findings suggest that, about 6.43% of the share of vegetation and 5.63% of built up have been inundated during the wet season.

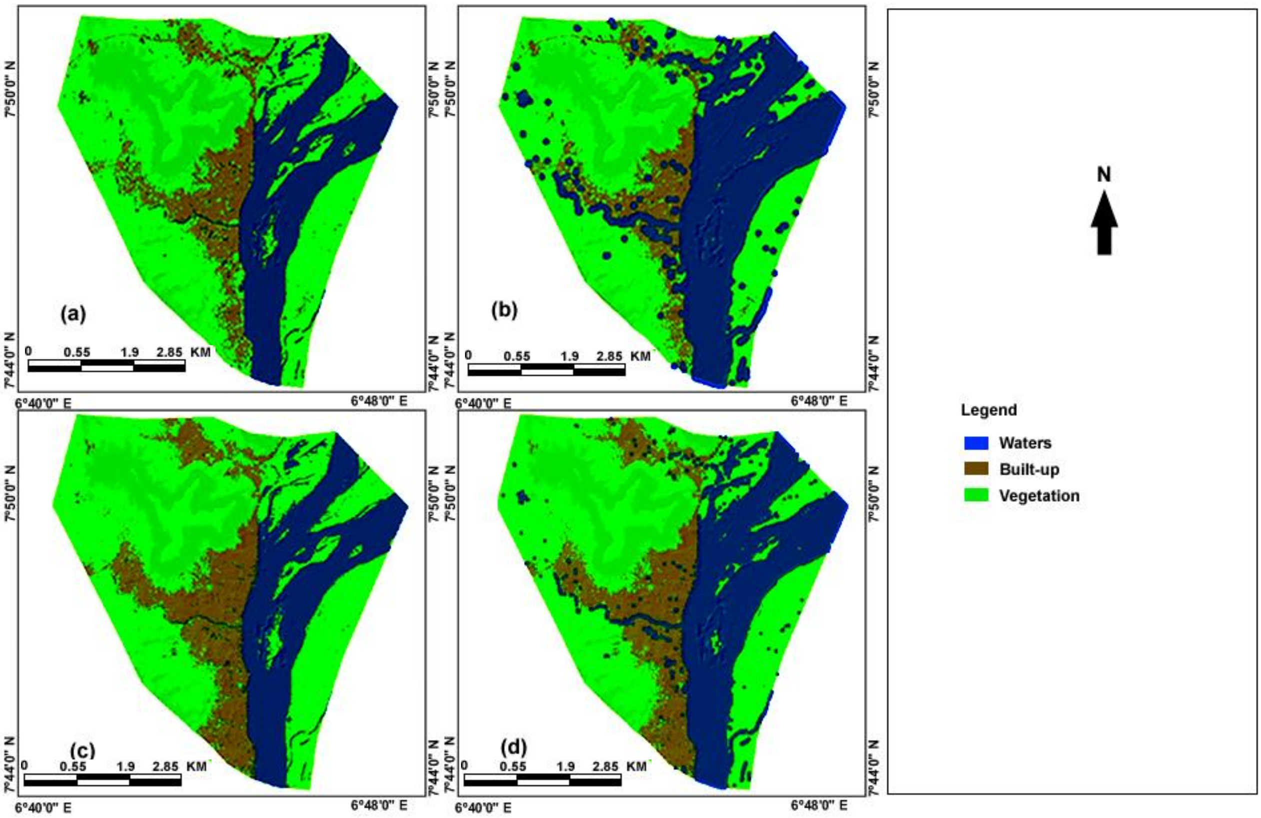

Figure 3. Composite Land Use Cover for Lokoja in 2012 and 2018. (a) 2012 dry season, (b) 2012 wet season, (c) 2018 dry season, (d) 2018 wet season.

Table 2. Seasonal Variation of Land Cover Change 1999-2018**.**

Seasons	**Dry season**		**Wet season**	
Year 1999	**Area (km^2)**	**Percent**	**Area (km^2)**	**Percent**
Water	33.62	22.13	35.22	23.18
Built-up	7.84	5.16	7.84	5.16
Vegetation	110.46	72.71	108.67	71.66
Year 2009				
Water	33.7	22.18	38.31	25.22
Built-up	17.5	11.52	17.5	11.52
Vegetation	100.73	66.3	96.1	63.26
Year 2012				
Water	33.6	22.11	58.08	38.23
Built-up	21.82	14.36	19.58	12.89
Vegetation	96.51	63.53	74.26	48.88
Year 2018				
Water	34.93	22.99	42.23	27.8
Built-up	27.72	18.25	26.16	17.22
Vegetation	89.27	58.76	83.53	54.98
Total	151.92	100	151.92	100

Source: Authors' analysis, 2018.

3.2. Discussion

The result shows that flood inundation's seasonal and spatial pattern has varied significantly over the study period. However, a drastic flood inundation was recorded in 2012, leading to about 23.05% reduction in vegetation and 10.27% in built-up. Overall, the effect of flood inundation was more intense on vegetation. The evidence from the study of Ifatimehin and Musa (2008) indicates that a significant portion of vegetated land in Lokoja is being used for agriculture. However, the studies of Buba et al. (2021), Umaru and Hafiz (2019) indicate that the destruction of agricultural land is one of the major effects of flooding in Lokoja.

Additionally, the submergence of highly productive agricultural land in the study area may lead to immediate and long-term losses of agricultural produce (Dasgupta et al., 2015). Furthermore, the legacy of soil salinity often established after the recession of flood waters may impair the growth of many crops (Shainberg and Letey, 1984). These could constitute severe impacts on the food value chain and the local economy (FAO, 2015) and livelihood.

The study also identified that flood inundation of built-up is gradually showing a decreasing trend from 2012 to 2018. However, its effect (in 2012 and 2018) poses a huge risk to life, cultural heritage, infrastructure, and property. For example, Buba et al.'s (2021) study suggests that impacts of flooding pertaining to developed areas in Lokoja include destruction of markets, transportation systems, housing, and water supply infrastructure. The damage has been done on the existing infrastructure and not potential damage before the reduction in the flood rate.

4. Conclusion

The magnitude, spatial and seasonal patterns of flood inundation for the study area for 1999 and 2018 are generated by modeling land cover dynamics for dry and wet seasons. The study finds out that flood inundation is more pronounced on vegetation. As a result, farmers in Lokoja are incredibly predisposed to poor agricultural production due to flood inundation. Accordingly, efforts to improve resilience against variable weather, flood inundation, and seasonal uncertainties should be encouraged. For example, investment in climate-smart agriculture, agricultural insurance, installation and improvement of existing drainage facilities, construction of river embankments, planting in areas that drain faster after heavy rainfall, and planting of agricultural crops that could tolerate a long period of land submergence is recommended. The method of this study could be a consequential tool for identifying flood inundation hot spots for flood control actions, estimating damage to infrastructure, agricultural produce, and properties (post-event monitoring of inundation events), and ultimately helping to formulate policies for sustainable physical and infrastructural development.

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