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Fluvial and geomorphological analysis of river dynamics and impact

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Abstract

Rivers are dynamic systems influenced by geomorphological and hydrological processes, shaping landscapes and impacting ecosystems. This study examines river channel dynamics, sediment erosion, transportation, and deposition, highlighting the interplay between discharge variability and sediment load in river morphology. It explores how sediment transport influences river stability and the consequences of excessive sedimentation, such as flooding and erosion. The research also discusses flood routing techniques, including hydrologic and hydraulic modeling, to predict flood wave movements and mitigate flood risks. The study emphasizes the significance of stream channel stability and floodplain management in sustainable land use planning, infrastructure protection, and environmental conservation. By analyzing sediment transport mechanisms and the effects of natural and human-induced changes, this research provides insights into river behavior and its implications for water resource management. Understanding these processes is essential for mitigating the adverse effects of flooding, improving flood prediction models, and enhancing resilience in flood-prone areas. The findings contribute to geomorphological research and practical applications in hydrology, engineering, and environmental management.

Keywords: Geomorphology; River dynamics; Flood routing; Sediment transport

1. Introduction

There is absolutely no feature on earth that is constant, even Man. The contemporary idea in geography, particularly in geomorphology, is to research the nature of change and determine what processes are involved in the change in earth features.[1]

1.1. River Channels Dynamics

Not all river channels have water flow throughout the year. Some channels are occupied by permanent streams that flow throughout the year, for instance, rivers Niger, Benue, Ogun, Osse, Osun (all in Nigeria) are all permanent streams. Some streams are irregular. Intermittent stream channels have water flow through them only during the rainy season, as the rain stops, they stop flowing.[2] Examples of these channel types are primarily found in the northern part of Nigeria, where the main source of water for streams is rain. The rainy period is usually between 3 and 5 months a year, so the channel will have water flow through for just that period.

Channel size is related to river discharge, but it is common for rivers to overflow their channels at flood stage.[3] This is because discharge cannot be predicted, particularly given recent global environmental change and high variability in weather conditions.

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1.2. Cause of River Channel Dynamics

The dynamism in river channels is caused mainly by discharge.[4] Should the continuous increase in the discharge amount persist, a meandering channel could later become a straight channel. River channels, like other terrestrial phenomena, are responding to global environmental changes.[5], [6]

Also, a braided channel could be re-shaped by discharge. Therefore, discharge can affect the channel load as well as its pattern. High discharge leads to a corresponding high energy. Most channels pattern at a point in time or a particular period of the year is not static. For instance, rivers in alluvial channels on the Great Plains have been observed to change from braiding to a meandering habit in response to decade-length historical climatic changes.[3]

It has been noted frequently that transitional forms are between wide, shallow channels with a braided habit and narrower, deeper channels that meander. Some reaches of alluvial rivers have changed historically from braiding to meandering or back, but the changes were sudden or unexpected. Lack of intermediate forms is related to the minimum threshold of sediment erosion on both. The condition is that, if the alluvium is non-cohesive sand or coarser sediment, rising velocity drags it as bedload, and a wide, shallow braided channel develops. If the alluvium is cohesive and smooth, an equivalent velocity increase may erode it, but is transported as suspended load in a deep, meandering channel form.[6]

1.3. Sources of water to the river channel

Unlike at the arid environment, the humid regions have the mean annual discharge of rivers increases downstream unless there are structural controls such as karst, which could be used in this case. Notably, there are three sources of discharge to river channel particularly in the humid tropics these are; rainfall or precipitation, ground water, highlands (Fouta Djalon highland – source of river Niger; Cameroun/ Adamawa mountains- source of river Benue).

2. Sediment Erosion and Transportation

2.1. Sediment Erosion

Rock minerals are not capable of handling contraction and expansion due to an inadequate coefficient of elasticity to handle equilibrium; therefore, fragmentation is inevitable. Sediment is a naturally occurring material that is broken down by processes of weathering and erosion and is subsequently transported by the action of wind, water, or ice and/or by the force of gravity acting on the particle itself.[7], [8]

Sediments are basically fragments of rock materials that come from the weathering of rock and are moved and deposited by rivers or ice. Excessive removal of earth materials or sediments from a geographical point to another region is called erosion. Erosion occurs where a stream has excess energy, particularly when it flows over unconsolidated or weakly connected rocks. The entire activity of fluvial activities on the landscape could be summarized as removal and deposition; this agrees with the geographic law (law of thermodynamics)- energy cannot be created or destroyed, but can transform from one form to another or from one place to another.[9]

2.2. Sediment transportation

When rain falls, the materials are dislodged and transported to the land surface. Streams and rivers act as passages for the movement of sediments, and when there is not enough energy to transport the sediments, deposition occurs.[10] In a fluvial system, of course, erosion of materials precedes transportation. Transportation involves movement of materials from one location to another. Mostly, energy is required by the rivers to be able to move these sediments from their positions. The energy rivers require to overcome friction is inseparable from the transportation energy. However, wherever the rivers encounter much friction to overcome, the available energy for transportation drops consequently. In other words, friction reduce the ability of a river to erode and transport, because the bulk of the river energy has been used up to come obstacles, it has been estimated that most rivers used about 90% of their energy to overcome friction thereby using the remaining (10%) to grab and transport materials. Weathered materials derived from the upland watershed or by plucking and abrasion in the channel, are carried by rivers.[11]

Rivers and streams carry sediment as they flow depending on the sediment supply along their course. When the eroded particles are carried by water in motion, sediment transport occurs. Depending on the settling velocity and the drag and lift force, these sediments are carried along the river in either suspended form or bedload. The greater the discharge and flow rate, the higher the capacity for sediment transport. Rivers or streams erode soil particles along their courses and cause erosion.[12]

The change in the trends of the suspended sediment loads in any river is persistently altered not only by human actions but also by various environmental variables. One of the reasons for an increase in the sediment concentration is soil erosion. Erosion usually increases the sediment discharge from streams coming from the catchment; but it should be noted that not all erosion immediately shows up as sediments. Much of it moves into various temporary storages in the watershed. The importance of additional factors in sediment generation in mountainous regions to include tectonics and seismic activity, glacial area, proportion of snow and basin area have been highlighted. [13], [14] Ali and Boer [15] Environmental variables such as topography, hydro-climatology, lithology, land use and soil erodibility affect sediment yield. Sediment transport is governed by the river flow, the particle size distribution, the river cross section, and temperature. Therefore, the factors affecting sediment transport can be broadly classified as;

- Hydrology
- Climate
- Geology
- Topography and
- Land use

Based on sediment transport capacity and the sediment supply, a river can be classified into

Reaches (**'reach'**, a segment of a stream, river, or ditch, generally defined from confluence to confluence, or by some other distinguishing hydrologic feature) as shown in Table 1.

Table 1 Classification of river reaches

Reach of the river	Sediment supply situation
Erosion	Transport capacity > sediment supply
Transport/Regime	Transport capacity = sediment supply
Deposition	Transport capacity < sediment supply
Delta	Transport capacity << sediment supply

Source: Sonam, 2009[10]

2.2.1. Forms of Sediment Transportation

Weathered materials supplied to rivers from landslides and mass-wasting are moved in different ways depending on the size and nature of the materials; here, nature means the composition of the sediments. [7]

Sediment movement in streams and rivers takes two forms, that is, transported loads in river channels are divided into three (Figure 1), these load types are:

- **Dissolve load-** these are compounds in solution or colloidal mixtures, e.g, limestone, clay, etc. Suspended load, these are solid fine-grained particles, e.g, sand. Suspended sediment is the finer particles which are held in suspension by the eddy currents in the flowing stream, and which only settle out when the stream velocity decreases, such as when the streambed becomes flatter, or the stream discharges into a pond or lake.
- **Bed load-** bed loads are coarse, grained particles. Larger solid particles are rolled along the streambed and are called the bedload. There is an intermediate type of movement where particles move downstream in a series of bounces or jumps, sometimes touching the bed and sometimes carried along in suspension until they fall back to the bed. This is called movement in saltation, in liquid flow the height of the bounces is so low that they are not readily distinguished from rolling bedload.
- **Sediment load-** Sediment size is measured on a log base two scale, called the "Phi" scale, which classifies particles by size from "colloid" to "boulder".

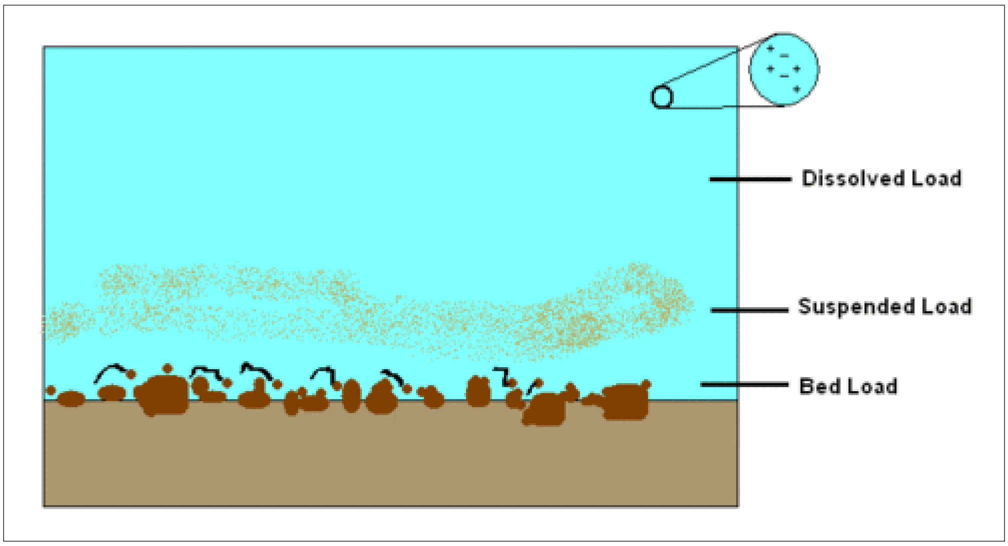

Figure 1 A schematic diagram of how the different types of sediment load are carried in the flow

Table 2 Velocity and Particles size

Sediments/loads	Particle size(mm)	Velocity capacity
Clay	.001- .005	15cm/s
Silt	.005- .05	15 cm/s
Sand	.05-2.0	0.5 km/hr
Gravel	2.0-500	1.2 km/hr
Boulder	>500	32km/hr

Source: Arthur, 1998

Rivers that drain heavily forested areas or overflow from lakes that act as settling basins tend to have mostly dissolved loads and are likely to meander (Arthur, 1998). This is because most of the energy has been used up in overcoming obstacles or being weakened by dams (lakes). Dissolved load has no detectable effect on stream flow. The concentrations average only 130 parts per million (ppm).[3] So, the solutions are too dilute to affect viscosity, turbulence, or the density of river water. Therefore, dissolved load, representing more than half the total work of fluvial denudation, gets a free ride to the sea by rivers where no kinetic energy is required to move it.

2.2.2. Sediment transport and related problems

It is necessary to know sediment transport in rivers and its effect on river morphodynamics. Aside from flooding, sediment in reservoirs could pose a big challenge to hydropower generation. Other than reservoir sedimentation (lowering the water amount), suspended sediment could also have an adverse effect on the turbines of hydropower plants, reducing their efficiency and, hence, electricity generation.

2.3. Erosion Models and Applications

Erosion model is a tool that allows one to calculate or predict average annual surface erosion and sediment delivery to channels in a standardized way. A typical example of modeling of a complex landscape process which requires combination of empirical and physics-based methods is soil erosion, and sediment transport and deposition modeling.

3. Introduction to Flood Routing – Hydraulic River Routing

Whenever a river overflows its banks, it is usually termed flooding. This happens when the river channel cannot contain the discharge supply to it, either from the storm water or the drainage basin. Floods vary in many ways based on their intensity and the devastation they cause.

3.1. Definition of flood

Flood is the temporal and or permanent covering of dry land by water. It usually occurs when rivers overflow their banks due to heavy downpour or the opening of a reservoir or dam. Floods often happen over flat or low-lying areas when the ground is saturated and water either cannot run off, or cannot run off quickly enough to stop accumulating. Where river water inundates or submerges an area of land that was formerly dry, such an event or scenario is referred to as a flooded area. Flood plains are sometimes used for agricultural practices, particularly during the dry season, due to their richness in fine particles, otherwise known as alluvial deposit. A typical example of a flood plain used for agricultural practices is the Nile River; other local examples are the flood plain of Ojo local government area of Lagos state.

3.1.1. Types of flood

There are three (3) types of floods, these are:

Flash flood

These are floods which happened within a short period of time, usually after a heavy downpour. It has been proven that flash floods are dangerous, it is localized events that often catch many people or an environment and even an agency by surprise. It is an expected event wherever it happens and is often over before an alarm can be given. A typical example is the Jos flood in the northern part of Nigeria, which happened in July 2012. It may also occur when a dam is opened.

Seasonal Flood

Seasonal floods usually result from snow/ice melt in colder climate regions. They are usually triggered by extreme warm weather. In other words, high temperatures in the cold regions trigger large volumes of meltwater that can be exacerbated by ice jams that block river channels. This is common these days owing to global environmental changes and high weather variability, where terrestrial temperature is on the increase.

Large flood

Large floods are caused by prolonged rain, perhaps due to hurricanes—continuous for days, weeks, or months at a time. For instance, a prolonged rain in Lagos in July 2011 and June 2012, respectively, resulted in a significant flood, affecting lives and properties. At this time, it rained for about 8 days continuously, but in different amounts.

3.2. Flood Routing

Flood routing is mathematically modeling the progress of a flood wave (or hydrograph) while it moves downstream.[16] Flood routing describes the movement of storm water from the upstream to the downstream point of observation. Flood routing also describes the magnitude of the flood peak, and when the peak will reach a particular region. When prediction is on the time and magnitude of a flood from one local area to another, it is simply referring to flood routing. The source of water to be routed could also be when a dam is to be opened. Early warning and mitigation measures are necessary to minimize the effect of social and economic activities, particularly when a dam is to be opened or when a large flood is envisaged due to heavy downpour. It is an integral component in any hydrologic model. It is the most important activity in predicting flood stages and discharges as functions of time and space along a river reach. It is used in predicting the characteristics of a flood wave and their change with time in the direction of flow

3.3. Characteristics of flood Wave and change

- Maximum water surface elevation and its rate of rise or fall (considered an important factor in the planning and design of structures across or along streams and rivers).
- peak discharge, which is required in the design of spillways, culverts, bridges, and channels sections,
- total volume of water resulting from a design flood to assist in the design of storage facilities for flood control, irrigation and water supply.

Understanding and predicting the effects of floods is one of the challenges facing fluvial geomorphologists. However, two general strategies have been developed for modelling floods.

3.3.1. Theories and Modelling Approach to Flood Routing

- **Hydrologic modelling**: this uses historical data with a simple conceptual model to make predictions. The historic data could be that a specific region gets flooded at a particular month of the year, or gets flooded every 5 years interval. Once this data is obtainable, it will enhance the adequate and accurate flood routing concept.

The "Muskingum" flood method is considered among traditional hydrologic approaches, the most extensively used and known in the studies of flood routing in rivers and channels.[16]

- **Hydraulic modelling**: This uses fundamental physical principles of flood flow to create a flood prediction. It requires the consideration of flood components such as flood wave velocity.[17]

In addition to the two techniques above, advancements in meteorology equipment through satellite monitoring of floods can be routed.[18], [19] This is usually done by the weather forecast department of the National Oceanic and Atmospheric Administration (NOAA) through very high-temporal-resolution satellites. For instance, the agency responsible predicted the flooding of Nova Scotia and Newfoundland (Canada) on September 10, 2012, two days before the events.[20]

3.4. Uses of Flood Routing

Flood routing is employed in practice for providing solutions to a variety of problems associated with water use such as:

- Predicting flood hydrographs for given or assumed initial conditions
- Determining hydrographs modified by reservoir storage
- Evaluating past floods for which records are incomplete
- Studying the effects of water resources development on the downstream flow conditions.

Depending on the location where it occurs, flooding is not necessarily a natural disaster. Flooding is a common environmental problem in coastal and hinterland lowland areas.

3.5. Approach to flood routing in Nigeria

The major approach (source of information) to predicting floods in Nigeria is mainly weather forecast reports from meteorological agencies such as the Nigerian Meteorological Agency (NiMet) and the National Oceanic and Atmospheric Administration (NOAA). The body saddled with this responsibility in Nigeria is the National Emergency Management Agency (NEMA).

4. Stream Channel Stability

A stable stream channel is defined as one whose morphological dimension or characteristics do not change over engineering space and time.[21] Stream channel stability is a practice aimed at controlling flooding and it includes practices such as straightening, dredging, clearing, snagging, and dam construction to help alleviate the problem of flooding. Alluvial channels are dynamic and adjust naturally to altered conditions, such as changes in base level or climate. The rate at which these channels adjust is related to the magnitude of the discharge and the channel gradient. The capacity of a stream to transport the sediment resulting from channel adjustment processes was termed "stream power" by Lane. [22]

Under natural conditions, channel adjustments usually occur slowly. However, when stream conditions are altered by channelization (channel shortening and deepening), both channel discharge and channel gradient can be dramatically increased. This results in increases in bed-load discharge and the size of transported bed-material, which, in turn, can cause rapid and significant morphologic change both upstream and downstream from the area of disturbance. In time, the channel adjustments may progress until the energy gradient of the stream approaches that of its unaltered state. Channel-bed degradation heightens and steepens the stream banks and causes channel widening by mass wasting processes. With time, channel-bed aggradation reduces bank heights and continued mass failures reduce bank angles, allowing bank surfaces to stabilize and become revegetated.

Channel degradation and widening proceed upstream along unmodified reaches and tributaries due to downstream modifications. In the case of dam construction, these processes usually migrate downstream from the dam.[23] Increases in erosion rates upstream lead to substantial aggradation downstream and loss of channel capacity. Assessment and prediction of channel morphology are needed to adequately protect existing bridges and culverts and to aid in the design of structures to be constructed along river channels.

4.1. Characteristics of a stable stream

- A stable stream is resilient to disturbances such as the passing of storm events and changes induced by humans.
- Characterized by a healthy, upright, and woody vegetation
- Low banks that are not susceptible to mass wasting (gravity failures)
- Flood plain that is connected to the river

source:www.Search?qriver+niger

Figure 2 Stable part of River Niger

Chorley and Kennedy,[24] described stability in terms of three types of equilibrium:

- static, in which a static condition is created by a balance in opposing forces;
- steady-state, in which the properties of a stream randomly oscillate about a constant state; and
- dynamic, in which a balanced state is maintained by dynamic adjustments.

Richards showed that in a natural, stable channel, channel dimensions constantly adjust to passing floods. So, although a stable channel has constant average dimensions over a medium timeframe (on the order of decades), those dimensions vary about the average value. See Figures 2 and 3

source:www.Search?qriver+niger

Figure 3 UnStable part of River Niger

4.2. Channel stability Assessment

It requires the expertise of a fluvial geomorphologist to assess the stability of stream channels based on observations of various parameters that describe the characteristics and conditions of the channel and the surrounding flood plain. This is to assess the current condition of the channel and to possibly identify the processes acting to change the condition over at least a reach level or the entire watershed system. The goal of the assessments is to understand the processes better so that stream restoration, bank stabilization, or a host of other river applications can be designed successfully.

4.2.1. Bank Erosion

Bank erosion is the wearing away of the banks of a stream or river. It is different from bed erosion of the watercourse, which is called *scour*. The roots of trees growing by a stream are undercut by such erosion. As the roots bind the soil tightly, they form abutments which jut out over the water. These have a significant effect upon the rate and progress of the erosion. (Figure 4)

sourc:.wikipedia.org/wiki/Bank_erosion

Figure 4 Bank erosion along Pimmit Run inMcLean, Virginia

Bank erosion could occur naturally, particularly in the face of atmospheric variations (Climate Change), but it could also be accelerated by human activities such as sand mining, dredging, etc. Erosion and changes in the form of river banks may be measured by inserting metal rods into the bank and marking the position of the bank surface along the rods at different times.

Bank erosion can be controlled by placing riprap (rock or other material used to armor shorelines) or gabions (concrete or sometimes sand and soil used in civil engineering and road building) along the river bank, as shown in Figure 5.

Figure 5 Riprap along Atlas Cove, Lagos, source field work 2012

On the Atlas Cove (Lagos) river bank, the method used to control bank erosion is rip rap, which has been protecting the area from bank erosion over the years. If not controlled, bank erosion could lead to flooding and loss of land area.

4.2.2. Suspended Load

Sediment movement in streams and rivers takes two forms. Suspended sediment is the finer particles held in suspension by the eddy currents in the flowing stream, and which only settle out when the stream velocity decreases, such as when the streambed becomes flatter, or the stream discharges into a pond or lake. The relative quantities moved in suspension and as bedload vary greatly. At one extreme, where the sediment comes from a fine-grained soil such as wind-deposited loess, or alluvial clay, the sediment may be almost entirely in suspension. The estimation of suspended load by sampling is relatively simple. Suspended load is carried in the lower to middle parts of the flow, and moves at a significant fraction of the mean flow velocity in the stream.

4.3. Estimating Suspended Load

4.3.1. Grab samples

The simplest way of taking a sample of suspended sediment is to dip a bucket or other container into the stream, preferably at a point where it will be well mixed, such as downstream from a weir or rock bar. The sediment contained in a measured volume of water is filtered, dried, and weighed. This gives a measure of the concentration of sediment and when combined with the rate of flow gives the rate of sediment discharge.

5. Flood Plains and Delta

5.1. Flood Plains

Flood plain is an essential product of stream deposition. A flood plain, like a valley, exhibits much variety in its many gradations from the initial floodplain scrolls of coarse alluvium to the broad flood plain of old age with its varied features. Sand and gravel are frequently deposited on flood plain areas during high discharge or flooding, though high discharge does not necessarily mean flooding. (Figure 6)

5.2. Delta

A **river delta** is a landform formed at the mouth of a river, where the river flows into an ocean, sea, estuary, lake, or reservoir. Deltas are formed from depositing the sediment carried by the river as the flow leaves the mouth of the river. Over long periods of time, this deposition builds the characteristic geographic pattern of a river delta.

5.3. Economic importance of flood plain and Deltas

There are benefits derivable from the fluvial features such as deltas and flood plains. Highlighted below are some of the economic uses of the flood plain and the deltas if harness wherever they are found;

- Agricultural uses, e.g, rice plantation, sugar cane plantation, etc.
- Industrial base (e.g, boat or ship building)
- Source of biodiversity
- Fishing ground
- Over time, the deposition serves as protection, preventing the flooding or ocean surge from destroying life and cultivated crops or farmlands.

5.4. Landforms produce by flood plains and delta

Outline below are the various land features produced floodplains and deltas:

- Channels bars
- Oxbow lake
- Point bars
- Delta bars
- Natural levees(low ridges that parallel a river course, they are highest near the river and slope gradually away from river)
- Flood plain lakes
- Swamps

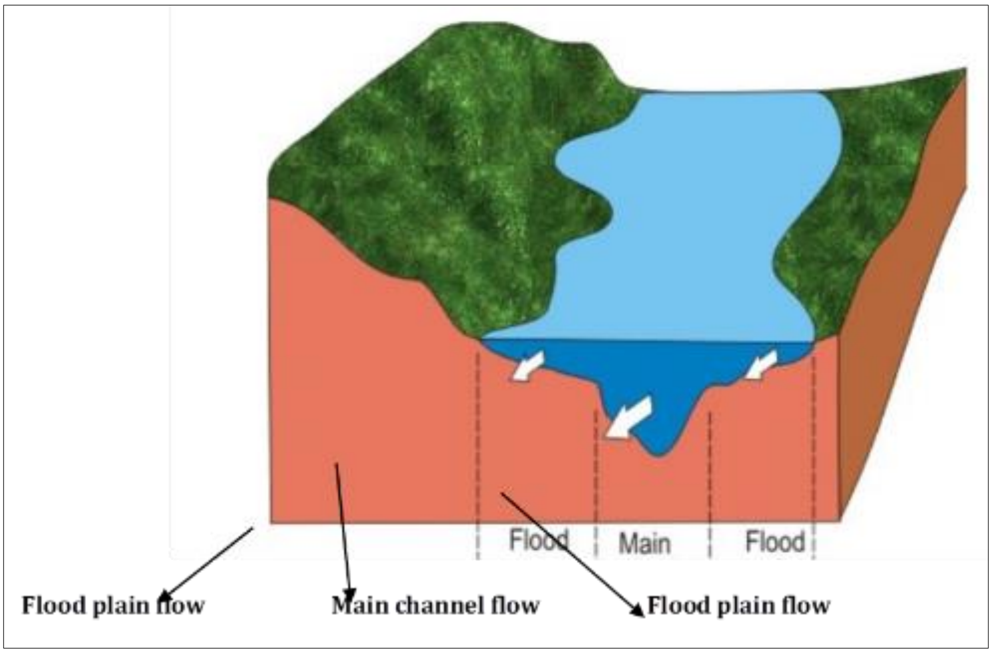

Figure 6 A river flowing its banks during flooding

6. Conclusion

Where there is much sediment covering the river beds, flooding is inevitable and if such flooding events become a frequent happening, it could affect bridges constructed across and nearby settlements just as the case of River Niger flooding Kpata, Adankolo and Gadumo areas of Lokoja state, Nigeria in September 2012. Therefore, the study of sediment transport pattern could be useful for bridge design and to warn of the settlement along the rivers wherever possible. A river reach is an aggregation of river links that identifies a section of river with relatively uniform physical characteristics. The process of computing the progressive time and shape of a flood wave at successive points along a river is termed flood routing. It is also known as storage routing, stream flow routing.

Flood routing techniques help us anticipate and plan ahead should a scenario occur in a river system. If the volume of river water increases, the magnitude and vulnerable areas that will be affected can be known, and thereby, a warning could be issued.

Flooding is not always a disaster. At times, it can be a great source of input for farming, for instance, when water mixes with the ground and creates "Silt," a good material for planting. Stream instability can be arrested using bank and bed stabilization structures.

Bank erosion could occur naturally, particularly in the face of atmospheric variations (Climate Change), but could be accelerated by human activities such as sand mining, dredging, deforestation, etc.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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