



ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
CHANNEL STABILITY ASSESSMENT AND STABILIZATION
MEASURE OF MERSA RIVER, ETHIOPIA

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of
Science in Civil and Environmental Engineering (stream Hydraulic Engineering)

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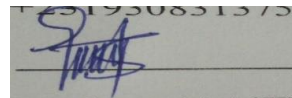
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ABSTRACT

Channel dynamically changes in response for the variation of flow and sediment transport. Sediment variation is because of land use change, composition of channel bank and bed material while for variation of discharge is because of climate change, as a result channel become altered. This channel change cause to flooding, channel bed and bank instability consequently destruction of infrastructure constructed along a river, irrigation area, home and other property in adjoining area. Assessing channel stability and provide stabilization measure is critical to prevent such damage.

The objective of this study is evaluating channel stability investigation and recommend appropriate mitigation measure of Mersa river, Awash basin Ethiopia. HEC-RAS5.0.7 model with BSTEM (its extension) was developed to evaluate Mersa river bed and bank stability, quantify in depth or mass sediment erosion amount and identify flood prone area. To achieve the objective both filed investigation such as river cross section data collected, soil sample taken and experimental tasks such as sieve analysis, triaxial compression test are carried out.

HEC-RAS model simulation with Yang sediment transport formula is best fit for study reach as compare to Meyer Peter and Muller sediment transport method. For entire simulation period an average aggradation was 1.24m and 0.98m at upstream and downstream reach respectively, whereas average degradation on both upstream and downstream reach was 1.25m. The average sediment eroded generated from Mersa river was 22.47kt/yr. Both aggradation and degradation were observed on the study reach but Mersa river reach more affected by erosion than deposition. Mersa river bank stability and toe erosion assessed by BSTEM of HEC-RAS was safe and again bank toe neither aggrade nor degrade in response to the flow. Additionally, Water surface of Mersa river was computed using steady flow analysis shows that flood over top above the bank, adjacent area (Mersa town) were affected by flood and the reality also true. The reality shows people around that loss their farm land and different property due to flood. Finally, this investigation presented that channel bed was unstable while bank was stable. Different stabilization measures like Gabion bank, Check dam and drop structure were recommended to prevent flood prone area from flood and to control channel bed instability.

Key words: Sieve Analysis, Triaxial compression test, Channel bed and bank stability, HEC-RAS model, BSTEM, Aggradation and Degradation, Stabilization measure

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ABBREVIATIONS

ASTM American Society for Testing and Materials

BSTEM Bank Stability and Toe Erosion Model

CD Consolidated Drained

CL Center Line

CU Consolidated Undrained

DEM Digital Elevation Model

HEC-RAS Hydrologic Engineering Center River Analysis system

LOB left over bank

LS Left Side

MoWIE Minister of Water, Irrigation and Electricity

MPM Meyer peter and Muller

ROB right over bank

RS Right Side

USACE United State Army Corps of Engineer

USDA United States Department of Agriculture

USGS United states geological survey

UU Unconsolidated Undrained

1 INTRODUCTION

1.1 General

River stability is crucial for both infrastructure development and people settlement. Since river is easily accessible sources of water for various uses (for crop production or irrigation, animal, for home, etc.) Even though river water has this much important but due to instability of river bank and bed which affect the environment by flooding over adjacent area it leads for losing of agricultural land, peoples house, their properties and hydraulic structure failure because of changing river courses. At the end socio-economic country development consequently adversely affected due to instability of channel.

It is stated that river's water usefulness and its effect on the area if it is beyond the limit then channel stability assessment be done to identify reasons for river characteristic's changes. River morphology changes due to fluctuations of channel discharge and volume of sediment enters to river and sediment leaving from river and dynamically by nature. Climate change and rainfall amount can be cause for discharge variation while the cause of sediment change mainly depend on compositions of river bed and bank materials.

Stream changes vary spatially according to the location of basin and affected by local variations in geology, soils, bank characteristics, vegetation, hydraulics and other aspects which influence stability such as numerous forms of land practice[1]. According to [1] Besides stream changes are inconstant in time dependent on the timings of inundations and draughts including land practice changes. Especially now a days the variation of climate by reason of the global warming which is becoming the cause for change the occurrence of severe floods and draughts; and land degradation [2] due to extensive deforestation for fuel wood production and in advance of cultivation in the catchment for rapid population growth, are leading to higher peak discharges, stream sediment loads and unstable rivers [3].

Urbanization of watershed, deforestation of trees, shrubs, bush for house fuel wood production, for agricultural area ... surrounding the river these all leads to consequences of sediment change (bank erosion or channel degradation and aggradation), runoff amount increase mean the river discharge changed.

The processes of degradation in channel banks often become steeper and taller due to degradation of the bed and destabilizing toe of bank [4]. This causes de-stabilization of the banks leading to mass wasting and channel spreading [5].

River bank catastrophe is an ordinary and anticipated phenomenon associated with the progression of rivers global. The evolution of river bank stability investigation has followed closely the development in systematic methods, examination tools, stabilization methods. Moreover, stability of river banks is a complicated issue which comprises geological study, landscape, stratigraphy, hydrology, weather, spatial difference and geotechnical engineering characteristics of soil [6].

The proposed case study area Mersa river situated in Awash Terminal, Awash basin and is prone to severe soil erosion difficulties resulted from a combination effects of rugged topography in the Mersa highlands. The area characterized by overgrazing, over-cultivation, over-exploitation of vegetation cover; erratic, intense, untimely and shortage of precipitation; and expansion of crop land to steep slopes growing staple food crops such as maize, mango, cotton, palm tree and onion. Based on Awash River Basin sedimentation modeling study, the total erosion generated from this sub-basin is 38.2 (Million Tons per Year) Mt/yr.¹ Awash Basin the one which affected area by erosion of soil [4], transport of sediment and degradation of land. In the basin land and water resources are in danger due to the rapid population growth, deforestation and overgrazing, soil erosion, aggradation of sediment, storage capacity decrease, drainage and water logging, flood problem, pollutant transport, and population pressure².

The study zone Mersa is flat and surround by mountains on the other hand the rivers slope is also highly steep any amount of flood causes for destruction on Mersa town. Totally Mersa river produces different problem on the peoples because of sediment deposition and flood over the area by losing the farmer agricultural land, properties, any hydraulic structure such as bridge, so these must be solved through assessing the river stability and providing appropriate mitigation measure. The research aims are to check the river stability and sediment aggradation or degradation.

¹ Source: *Awash River Basin Authority Report, June 2017*

² Source: *The impact of disaster risk management interventions in humanitarian programs on household food security by Shimeles Hailu, Woldia 2013*

Therefore, assessment of stability problems of these river reaches is very essential for implementation of proper stabilization measures.

1.2 Statement of Problem

Channel instability problem causes to a sequence of damage on a country because it leads loss of property such as (people's houses, agricultural land) failure of hydraulic structures which were constructed across a river. So, investigate channel stability is obligatory to prevent damage due to river bank and bed instability. Firstly the necessity of stability assessment is in Ethiopia we have been face in bridge failure; the failure cause mostly categorized under two broad class the first one structure failure i.e. construction material problem, cement sand proportion problem extra while the second one is instability of bridge abutment these remains due to lack of channel stability assessment but assessment of channel stability is done and provide desired mitigation measure it can be minimize the bridge failure due to stream bank instability. Assessment of channel stability analysis not enough before bridge construction but continue until the life span of the bridge. The second necessity of channel stability assessment if river situated in between a village of towns it's adversely affects adjacent area through excess flood washout the farm land, destruction of people and other properties. Therefore, in order to protect bridge or road failure and to prevent damages on people's house, agricultural area etc. assessment of channel stability is vital. All the above discussed damages have been happened on the proposed study area in the previous years so this need to be evaluated by assessing the channel stability. In addition, Mersa river starts from mountains then its slope is a highly steep and it crosses the Mersa town by dividing in to two so these steep slope leads to transport sediment material when flood was occurred and on the river left side by changing its course consequently erode the whole agricultural land and now farm land is covered with sand. Additionally, people's live on these side again faced several challenges such as who had lost their farm land now made extract sand and sale for construction agency in order to feed themselves whereas their house also on its edge in the coming few years it would be demolished by flood. So, the aim of these study is to assess the channel stability and recommend appropriate measure which is essential for town development by preventing properties damaging and infrastructures along the adjoining areas thus, it should be controlled and managed properly.

1.3 Objectives

1.3.1 General Objective

The general objective of this research is to assess the channel stability in response to varies discharge capacity and sediment accumulated which comes from the catchment.

1.3.2 Specific Objectives

The specific objectives are: -

- ✓ To assess channel stability of both the bed and the bank.
- ✓ To appraise flood zone extent corresponding to different discharge with different return period.
- ✓ To study extents of instability problem in the Mersa town.
- ✓ To recommend appropriate mitigation measure for stability problem.

1.4 Significance of the Study

People everywhere in the world lives near to water that can be earned simply one of the sources to get water is river and they settle around natural river. River stability is essential in both settlement of people and construction of hydraulic structure along or across a river. Therefore, channel stability assessment plays a vital role to providing in designing, constructing and maintaining river training structures for instability problem. Generally, this study for Mersa town gives clarification the channel stability conditions and what measure should be taken for its adverse effect on the area by quantifying the channel vertical change or channel bank stability in addition to people faced challenge due to channel instability.

1.5 Scope of the study

The scope of this research is including assessment of Mersa river reach contains channel bed change, channel bank stability, floodway delineation and recommend on reach which have a significance adverse impact on the people live near to the river. The bill of quantity, selection of each construction material, cost of stabilization measure not included in this paper since main goal is to assess the stability condition and recommend mitigation measure.

2 LITERATURE REVIEW

2.1 River characteristic's

Rivers are the furthestmost exciting creatures on Earth- they are wild and self-regulating, they are friendly and hazardous, and they are impressive and fragile [7].In modest terms, river is bodies of water with contemporary moving in one overall direction. It can different in size, through smaller forms of rivers being mentioned to as streams, creeks, creeks, brooks, licks, torrents, gills, flows, burns, or runs[7].

River classifications can be well-defined in to many characteristic parameters including channel slope, cross-sectional geometry, sediment weight and size, and planform geometry. Changes to one variable often means that other river features must be altered up to reach some sort of equilibrium. Channel outline is river characteristic that often refers to planform geometry, the path that river takes as it moves to down gradient direction [8].

Morphology of river and morpho dynamics are issue to main conditions that involve of the quantity and temporal flows of water, the amount of sediment entered into river, the river bed and river bank nature of constituents and flora, and the river geological and topographical situation, including gradient of landscape, weather and human interfering. Water flows established the measure of river and sediment regime gives individual character to river evolution [9]. Finally, rivers can usably be categorized on the criteria of scale, sand calibers and slope, leading to steep distinction, middle and low longitudinal slope channels which generally parallel to high, middle and small channel border roughness. Channel variations connected with downstream passage rivers morpho dynamics sediment constitute. Principal morphodynamical effects contain deformation, division, and channel degradation. A fundamental experience is which rivers conveying a weighty charge of bed sediment material essentially have a sideways system of instability: channel lateral displacement is a usual part of rivers equilibrium function. Hereafter the required river zone is more than the presently lively channel. Consequences of this situation are taken in account with context of river refurbishment and channel management [10].

The river natures are existing in a diversity of forms, for instance conventional, sinuous, bendy, and braided, because of interacting processes among water flow, sediment conveyance, and vegetation. Anthropogenic activities can harshly modify these processes often resulting in

undesired and unanticipated consequences at a variability of spatially and temporally levels. This alteration causes safety problems, environmental hazards, or environmental degradation, with enormous resources and economic damages for the whole society [11].

Rivers continuously shape and restructuring their channels through erosion of the river bed and banks composition of material and the change and aggradation of sediments. For instance, erosion and decline of the banks can cause to channel widening. Channel bed Scouring deep the channel, whereas sediment deposition decreases depth and can cause to the channel bars formation[7].

According to [7] there are four kinds of alluvial channels these are straight, meandering, braided and Ana branching. Straight channels: - While there are many examples of rivers which had been artificially straighten out for river training work, naturally straight channels are rare. Even if, river exists differences are usually realized in flow outlines and bed elevation. Straight rivers are relatively not-dynamic, with rates of stream migration restricted by a blend of less energy availability and good bank strength. This is accurate where river banks are shaped from more hardy material, such alike consistent silts and clays.

Meandering channels: - Meanders rivers forms in a diversity of substratum and sandy bedrocks. Accompanying with reasonable stream powers, alluvial meanders can advance in gravels, sands, or fine-grained soil. An exciting meanders characteristic is that they are scrambled to channel scope, being more extensively larger channels spaced. The degree of meandering differs greatly, after channels which only diverge to some extent from straight contour to arrangements of highly long-winded meander bends[7].

Braided channels: - it is considered by extensive, moderately shallow, streams that the flow gaps and responds around bars also islands. Braided river appearance differs with varying flow circumstances. At a time of high flows, channel bars become partially or wholly flooded, giving the entrance of single widespread channel. During low flows, wide areas of bar external can be visible. Braided rivers, are connected with high flow of energy expenses, that is involved in the conveyance of excessive sediment volume. It is extremely active, with common shifts in position of channel. Amendments, such alike the partition and reconstructing of bars and the construction and change of new bars, ensue over relatively rapid time period start from days up to years [7].

Ana branching: - channels ana branching rivers, where flows are divided into two or more discrete streams, are comparatively occasional in compare to the previous channels. The discrete channels, known as anabranches, are characteristically divided into floodplain, distributing it into a different of large islands. Discrete anabranches could it might be straight, meandering or braided. As compare to braided channels, channel side rates migration is characteristically very low. The island is constant features and, responsible on weather conditions, are frequent healthy vegetated. Nevertheless, new stream may be divided during flood break the stream boundary and fall out in floodplain. The remaining streams are uncontrolled as flows are diverted somewhere else, or as rapidly it becomes aggraded with sediment [7].

The stream network and river morphology are depending on relations between geographical situation and water flow over catchment from higher to lower elevations. The interaction takes in the entrance, conveyance and aggradation of erodible material from river borders and is shaped by the intrinsic potential energy to the river system formed due to the difference in elevation from the higher to the lower bottom part. This potential energy changes a multifaceted fluvial network as the river moves through the landscape. Excess energy is dissolute by many means, including: contact with instream and channel bank vegetation, turbulence within the channel contours, erosion at meander turns and most significantly through the conveyance of sediment. Sediment productions are affected by many aspects, and the watershed over which the channel flows affects the form and quantity of sediment produced. Kind and cover of vegetation, land practice, soil category, climate and erosion frequency are vital in production of sediment and conveyance and the weighting of their influence may change laterally the longitudinal profile of channel system. Sediment conveyance capacity and sediment load are also key factors which influence channel form and process. Sediment transport capacity is powerfully influenced by flow rate and depth of water and velocity itself is regulated by the channel slope, geometry, discharge in addition to channel roughness. Any changes to these parameters would affect the ability of river to transport sediment and riparian flora plays a role in various of the procedures controlling these parameters[12]. Sediment load is the over-all amount of sediment being transported and may be as dissolved, suspended and bedload. Bedload's are considered as form of sediment most influential in channel change pattern and stability [13].

2.2 Channel Stability

Channel stability is defined as slight alteration in the usual bed elevation, cross-sectional extents, and sinuosity over period. Stability can be attained in a channel reach when the amount of entering sediment equals the quantity of leaving sediment within a time. On condition which there is no tendencies or dramatic changes in watershed situation, channel dimensions tend to vary around regular values in what has been known as “dynamic equilibrium”. It is a significant requirement to achieving proper ecology [14].

Channel stability must be demarcated in relationships of both temporal and spatial. Thus, temporal with spatial scales used contrast depend the application. Temporal scales to stability of river can start from medium, on which one might be worried about bridge safety or ecological recovery, to long period, which would contain geomorphic and geologic stability. A general timeframe is taken to be at the sequence of one to two years for short; in the range of ten to hundred years for medium, typical of engineering design lives; and hundreds up to thousands of years to long-term. Spatial scales can also vary broadly depending on how stability is quantified. Channel stability is a combination of levels of trouble to flow condition and sediment discharges, and susceptibility of river to change. In every physiographic region, the disturbance that began the extreme impairment to the streams was the grouping of cattle activity, vegetation elimination or afforestation, and channel flattening. The integrated effect of these activities was poorest where cattle had direct access to streams. Also, weakness of channel banks to erosion significantly obstructed the level of damage [15].

Stabilization of Stream is defined as: “the in-place stabilization of severely eroded streambanks and streambeds to improve water quality, biologic and chemical processes, and uplift of ecological process.” Stabilization techniques may include both soft and hard engineering methods along with in-stream structures with the long-term goal of improving the aquatic resource [16].

The stream stability states to how it withstands itself to the flowing discharge and sediment weight. Generally, stable channel might change its boundaries nevertheless not show trends in variations to its geometric characteristics. Some form of river instability happens in which the river is incapable to conveyance the sediment load sediments aggraded in the river cause to the situation indicated to as aggradation. When the capability of the channel for conveyance sediment surpasses

the obtainability of sediments within incoming flow, and stability beginnings for the material shaping the border of channel are topped, erosion occurs [17].

Stream channels exist to abandon water from earth surface. The flow of water might also initiate earth materials so as for streams, to a higher or lesser degree, shape their channels. The consequential channel form and channel history changes depending on principal governing conditions. the volume and time delivery of flow that is providing from upper part and the earth surface, volume, timing and caliber of sediment which is announced into the river, the properties of bed and bank materials, containing vegetation, through that the river flows the geological past of the riverine land; in precise, the topographic gradient down that the water with sediment are transferred [10].

A stable river in neighborhood of bridges are one in that association between geomorphic progression and form is inactive and the channel morphology of classification remains relatively continuous over the short-term from one to two years, over a short distance upstream and downstream from bridge, and with nominal lateral movement [15].

According to [18] Rivers can show an extensive range of replies to changing involvements of flow, sediment, and vegetation over human time scales. Channel retort might range from small scale adjustment of channel physiognomies grain size, width, depth to large-scale adjustment of reach morphology and planform pattern.

Channel instability is one of major constraints in the investigation of stream engineering such as injury of life and goods can occur. It can arise both in human-made or natural channels all over the world. Channel instability connected to lateral and elevational variations in the channel bed, which causes to successive problems for both the usual and artificial environment: Intimidations to roadways, utilities, development in the geomorphologic floodplain, Property loss because of migration of channel, Trout habitat loss, due to the change from a pool-riffle sequence to mainly speeding water in continuous riffle sections, Riparian zones and wetlands loss due to high width-to-depth ratios and passage of lateral bank [19].

Channel instability, consequences of distraction of the channel equilibrium, is characterized as follows: Vertical Instability, leading to differences in the river bed elevation level in to deposition

of bed material or degradation of the bed material. Lateral Instability, where deposition or erosion in channel banks causes the small flow stream location to move horizontally [19].

Instability happens when the river moves laterally, stream bed level is elevated or dropped, thereby forcing variations due to water flow, specifically in the flooding condition. This instability can cause to many harmful impacts including river damages on property and buildings, alteration in floodplain, buried utility lines exposure, scouring under piers of bridge, increased and decreased sediment amount of river, declining bank stability, reduced aquatic habitat, demolished wetlands and riparian flora, and minimize recreational opportunities. Development and river system existence are encouraged when channel regulations and fluctuating river situations are more manageable and predictable. Restoration of channel is compulsory when conditions have produced a channel to become unstable short and snappy where it becomes unmanageable [19].

River instability needs to be evaluated on both temporal and spatial scales. Instability of river is also essential to identify natural geologic loss and conveyance mechanism against anthropogenic impacts [20]. Succeeding major floods, due to necessities to provide inundation damage restoration plans, different scholars studied alluvial bed streams for gradients smaller than 0.02 somewhere the pre- and post-flood morphological parameters were the same. Different reaches, which were in poorest stability situation prior to inundation, exposed to foremost harm by the identical flow. Stable channel reserved as a reference reaches for the event of data were composed on channel materials, profile, dimension and pattern. The widespread sediment material and matching with record flood fixed not produce instability. The channel preserved its profile, dimension, and pattern and ensured not degrade nor aggrade. Deposition of sand happened in the river stream and within a some of years the sand was directed through without the net consequence of aggraded. This stream is one of numerous examples where scholar has field indication where post instability of flood did not happen, even if these channels had possibly erodible soil in its bed and banks material. Reference reaches for example this become a skeleton of the variables connected with constant natural channels. Stream which had been inappropriately succeeded and have meager riparian plants are exposed to enhanced channel bank degradation and consistent channel changes following to instability. The outcome of widespread range of stream instability can be cleared and computed through a progress of stream types in figure under seen lower [20].

The main challenge in the valuation of channel stability is to regulator the evolutionary state and procedure of the channel. The cause of the instability is as essential to understand in accumulation to the consequence. It is imperative to realize the devices initiating the change in morphological parameters and stability guides to protect or to precise instability of stream channel [20].

Present human land usage activities are changing many components of land of the channels, consequential in unstable channels. Instability have direct negative consequences to water quality, aquatic habitat and riparian habitat, and on channel-related man-made infrastructure such alike bridges, highways and structure of hydraulic like weir barrage dam. Resource management agencies should be recognized rapid bioassessment studies to support assess stability in a quick and cost-effective technique [21].

Channel morphology is the consequence of common interactions of four wide categories of parameters such alike fluid dynamics that include shear stress, discharge, roughness and velocity, channel conditions or channel formation including channel width, pattern, slope, depth, shape, etc., sediment erosion or deposition and sediment of channel bed and bank arrangement and character that is gravel, medium coarse, fine [22].

2.3 Causes of Channel Instability

Channel symmetry has been disturbed through for continuous years by development encroaching based on the stream and the building of embankments to prevent property from intrinsic flood hazards. Embankments limit the width of stream during in time of flooding and avoid the channel from increasing laterally on meanders stream. There is strong indication that once embankments are built along the certain bank of river, on the reverse bank erosion of bank can occur. Separate efforts to regulate and control the stream on one location may be cause succeeding damage in another area, which making the whole reach become unstable [19].

The following topography and issues have recognized as contributors to instability of channel [19]:

- ✚ Inadequate Streambank Protection (Unstable streambanks, Damage to riparian vegetation)
- ✚ Excessive Longitudinal Channel Slope (Steep stream slope, Straightening the channel)
- ✚ Flood Protection Embankments - Constructed embankments installed within the valleys to protect river shore property from intrinsic flood risks can focus excessive energy of the river in contradiction of river bed across and the channel banks and below from the restricting

structures. This is additionally causing to accelerated degradation of river bank and a reduction in channel diversity. As a result, a difficult percentage of speeding riffle sections or lower proportion of slack pool sections.

- ✚ High width to depth ratios
- ✚ Vast sediment load supply - To excessive deposition downstream contributors are the cause of coarse sediment from all the upstream watershed and from erosion of the channel bank and channel bed [19].

According to [23] many reasons could be sustained for channel instability some of those are: - vegetation deforestation on river edge either for fuel or for other purpose even though the importance of plants is varying affording to its kind and the region mainly it is strong that vegetation reduces the stream size of the normal river once the shrubbery is removed the water that can be consumed by vegetation to channel without any obstruction these leads increase in discharge on the river, sediment entrance or exit from the channel would be changed, bank material which supposed by the plants enter to the river or simply the bank could be eroded consequently the natural river become unstable. Generally [23] achieve that furthest common causes are for extreme degradation is urbanization and base level change.

2.4 Channel Characteristics change

Consecutive, overlying, spatial and periodical scales of river morphologic reply in alluvial stream contain [18]: -

- ✚ Grain size-scale change, including: local differences in particle size distribution, and friction angle, growth of micro-grain forms such as, particle collections, stone cells, and formation of textural covers that is grain-size facies.
- ✚ Variations in the type, size, and occurrence of river bed landscape, extending from micro-bed forms such as ripples, bedload material; to macro-bed forms or channel elements such as individual bar, riffle landscape, step, and pool.
- ✚ Different channel geometry that is alteration in resident cross-sectional width, depth, in addition to downstream variation of those topographies.
- ✚ Changed stream slope because of reach-scale aggradation and differences in channel sinuosity.

Greater scales of channel reply reproduce the total action of smaller-scale progressions, predominantly sediment conveyance of bed soil and bank materials. Later evolution of consecutive scales of response can be intended, with grain-size change existence the beginning order response. Additionally, because alluvial rivers show mutually regulating channel features, changes at all one parameter can impact all of the others [18].

2.5 Stream Restoration

River is natural state able to adjustment its form and topographies to in cooperation system-scale drivers and local situations [24]. According to [23] stream restoration is defined as the seeking of return for situation which existed in the earlier. Stream restoration also under [16] definition restoration means backup the lost natural service from current situation for example lost agricultural area due to stream instability by restoring the stream using different techniques return the agricultural area to its previous function. Stream restoration can be different depend on alteration type of stream i.e. if channels are aggraded the restoration would be to provide mechanism that sediment moves away from river on the contrary if stream is degraded the restoration techniques must be treat the river bed material. Generally, channel stability of natural stream is accomplished when a stream takes a stable cross-sectional dimension, horizontal alignment and vertical alignment. Restoration techniques may include river training structures to simplify the long-term goals to recover water quality, biologic and chemical processes, and uplift of ecological functions and services. In-stream structures used for restoration or stabilization projects are typically required to resist the bank full flow velocities and usual shear stresses. In-stream structures, if appropriately planned and constructed, had the capability to deliver the following benefits: Channel Bed/Bank and Floodplain Scour Protection, Improved Hydraulic Conveyance, Effective Sediment Transport, Habitat Creation or Enhancement, Nutrient Processing, Biogeochemical Processing, Utility/Infrastructure Protection, and Aesthetic Enhancements/Blending into the Existing Landscape. The functional goals have been recognized to evaluate restoration best management practices. Those are: In-Stream Grade Regulator, Streambank Guard, Floodplain Defense, In-Stream Habitat Improvements, Riparian Habitat Improvement, and Water Excellence Improvement [16].

According to guide line prepared by [25], Stream restoration is well-defined “the progression of changing an unstable, transformed, or degraded stream passage, including neighbor riparian region and flood-disposed areas to a stable situation taking in to account current and upcoming watershed situation. This process also contains returning: a stable dimension, shape, and outline, biological and chemical integrity, and the ability to transport water and sediment in a dynamic equilibrium.

According to review vegetation effect river stability by [13] the most widely used stream restoration techniques is riparian management in addition to stock exclusion, installation of off-stream watering points.

Restoration techniques are functional to assist retrieval and fast-track the re-establishment of both natural physical and environmental progressions. It can't be possible to reestablish a channel entirely to its former situation, owing to variations in the drainage basin, which modify the flow and sediment regimes. Nevertheless, a new situation can be recognized wherein natural function is restored. Restoration practices can be inactive or active. Passive restoration encompasses addressing aspects that are avoiding recovery, such alike actions within the basin that harmfully affect quality of water, sediment and flow regimes. Illustrations of passive restoration take in the establishment of buffer strips – zones of natural floodplain plants alongside the channel and return of the flow regime. Active restoration is when precise adjustments are made to accelerate retrieval, such alike the morphological rebuilding of meanders, riffles and pools [7].

2.6 Shear Stress

Fluid Shear stress can be defined power per unit area in the flow direction. When shear stress of fluid is better than the resistance force of the bank and material (soil particle) then as a result the channel become unstable. Critical shear stress (t_{cr}) can be defined by equating the applied forces to the resisting forces [17]. According to [26] studied Shear stress of water apply on stream dimension causes to erosion of the channel bed and banks.

The central factor that causes for instability natural stream is initiation of channel creating bed and bank materials cobbles of the channels. When these great particles start to move, they roll and bounce laterally the riverbed bottom disrupting the complete channel boundaries. Material moved in the channel bed which is called Bedload and is belongs to stream instability for the channel. Finer materials of clay and sands are simply conveyed in suspension because of large stream power

known as Suspended Load, and remain not found any more on the top bed layer. Suspended sediment influences water quality, but is minimum of a concern in the stability of channel on the natural channel than bedload. Meanwhile instability initiates only once these channels starting cobble materials move, channel stability can be well-defined by employing bedload transport equations. Transport of bed particles happens when drag forces determined as Shear Stress generated by flow along the stream bed material surpass resisting forces of the bed and banks and the particle weight. Shear stress on bed and bank materials is principally a function of two factors: these are mean flow depth and the gradient of the channel actually. Once the threshold for Incipient Motion is exceeded, the majority of materials which include the surface layer of the channel bed begin transporting. At which point, horizontal or vertical regulator of stream is reduced. Consequently, an instable braided or meandering channel shape, which methods when high flows initiate the coarse bed material. The channel arrangement permanently regulates toward an equilibrium. It makes those changes through lateral channel movement, and longitudinal profile alteration that is vertical aggradation and degradation. In reaches where the floodplain expands or the channel gradient levels, fluid stresses are minimized and the bedload is aggraded. These oscillations in sediment transport volume reason for cobble-bed materials of channels to be unstable as the bedload passages in pulses [19].

Approaches to describing erosion possible can be positioned in one of two groups: maximum tolerable velocity, and tractive force or critical shear stress. The previous approach is helpful in which velocity is variable that may be determined within the flow. Shear stress can't be directly measured – it must be calculated from other flow variables. Measure fluid force on channel boundary using Shear stress better than by velocity [17].

According to [27] studies shear stress explained as discharge in a channel exerts forces on the soil particle of the bank and stream bed. these forces may be sometimes great enough to dislodge some soil materials, transport them and deposit downstream. These leads to channel aggradation or degradation and the force causing called tractive force. Lastly this force divided by unit area is called shear stress and it is given by: -

$$\tau = \gamma R S \text{ Equation..... 2-1}$$

where:

γ = specific weight of waters, N/m³

R= hydraulic radius (flow depth for wide straight channel), m

S=hydraulic gradient, dimensionless

τ =shear stress

2.7 Hydrological Methods

Hydrology is applied every field of engineering concerning consumption and regulation of water resources. It is used for determination the size of structure storing, controlling or conveying natural flows. According to [28] hydrological data needed for estimation design flood discharge in stream are; Catchments long year records of precipitation data, River flow histories in the river where implementation of scheme required, The catchments features like land habit, plantation situation, infiltration and soon and Watershed map to be evaluation concentration time. Again [28] describe different methods for determining of design flood or calculating ultimate discharges to various return intervals few from all are the discussed below and selection of a convinced method depend on the project objective, data availability, and the standing of the project. Additionally, the rational method is appropriate to small-scale (< 50 km²) catchments and the unit-hydrograph technique is normally limited to moderate-size catchments through areas less than 5000 km².

2.7.1 Rational Method

It takes a rainfall of similar intensity and too long period happening through a catchment. Runoff amount progressively increases within the range zero to a constant value. When more flow from distant point to the catchment outlet in this case the runoff become increase. This time taken needed to flow travels from the distant part of the reach to watershed the outlet as t_c = concentration time, it is clear that if the rainfall continues beyond t_c , the runoff will be constant and at the peak value [28]. The peak flow of the runoff is determined by

$$Q_p = C * I * A \quad \text{Equation 2-2}$$

a) Time of concentration

Accordingly [29] suggestion concentration time estimated as discussed next equations depend on flow type and land conditions.

✚ Determination of Concentration time to Overland Flow

Overland discharge flow is the category of flow which happens in small, level or in upper reaches of catchments, where there is no obviously distinct waterway. The kerby formula is suggested for the determination of Tc in this case. It is only valid to parts where the gradient is fairly uniform.

$$T_c = 0.604 * \left(\frac{rL}{S^{0.5}}\right)^{0.467} \quad \text{Equation..... 2-3}$$

Where: Tc= concentration time (hours)

r = coefficient of manning (dimensionless)

L= catchment hydraulic length, which measured along flow track from the watershed borderline to place where the flood needed to be estimated (km)

S=Slope of the catchment

H = farthest point height above outlet watershed (m)

✚ Determination Concentration time to Defined Watercourses

The suggested empirical formula to estimating time concentration in natural river was advanced in US Soil Conservation Service

$$T_c = \left(\frac{0.87L^2}{1000 Sav}\right)^{0.385} \quad \text{Equation..... 2-4}$$

Where: Tc =concentration time (hours).

L = catchment hydraulic length, which measured along flow track from the catchment borderline to the point where the flood required to be determined (km).

Sav= mean slope (m/m).

✚ determination of Concentration time to Urban Areas

In urban watershed, concentration time must be calculated, where valid, through water flow velocities accordingly Chezy or Manning's equation over demonstrative cross-sections with representative slopes.

b) Runoff Coefficient (C)

It represents the collective effect of watershed losses and hereafter depending on surface nature, land slope and rainfall concentration. The significance of rainfall intensity is not well-thought-out in the available tables of values of C.

$$C_e = \frac{\sum_{i=1}^N C_i * A_i}{A} \text{ Equation 2-5}$$

where A_i = extent of sub area from total watershed with i having coefficient C_i and N = division number of areas within the catchment.

2.7.2 Empirical Equation

It is used for determination of the peak discharge and critical regional equation rely on arithmetic relationship between observed maximum flow and watershed characteristics [28]. This equation is applicable for a region which are advanced and for catchment that may give approximate value. The equation by different scholars are presented in the below in table

Equation developed by	Formula	Coefficient
Dicken’s	$Q_p = CDA^{3/4}$	CD range between 6 to 30
Ryys	$Q_p = CRA^{2/3}$	CR range between 6.8 to 10.2
Admasu Gebeyehu (Ethiopia)	$Q_p = 2.44(A)^{0.68}$	Area ranging from 200-9980km ²

Where A and Q_{max} denotes catchment area km² and peak flow m³/sec estimated by the equation respectively.

2.7.3 Hydrograph Method

To determine design discharge for scheme by the using unit hydrograph, design storm desired. Unit Hydrograph is widespread technique to calculate flood hydrograph to recognized storm. It is a graph of direct runoff result from unity depth rainfall homogeneously happening on watershed in continuous rate with fixed time duration. It relates direct runoff with precipitation surplus which means equating the effective rainfall volume with amount of runoff generated from its. This hydrograph technique is convenient for catchments area ranging (25 to 5000 km²). All the above

technique not used in one or more of its constraints for this study so the frequency analysis is the remain and popular method to estimate the flood discharge.

2.7.4 Flood Occurrence Analysis Method

According [28] Hydrological progressions like floods are extremely complex normal events. Different numerous parameters outcomes from such vents is difficult to model analytically such as flow in watershed is dependent on catchment features, precipitation and antecedent situation as a result design discharge calculation become very sophisticated problem which leading to numerous different approaches. The earlier discussion hydrograph and empirical equation is some of this. Additional method for forecasting of flood flows are applicable to for the rest hydrologic parameters like a precipitation are frequency analysis statistical system. The values of yearly extreme discharge for certain watershed with various successive years establish a hydrologic data sequences known as annual series. Commonly used frequency distribution functions to forecasting of maximum water flow are Gumbel's extreme-value distribution, Type III Log-Pearson distribution and Log normal distribution [28].

2.8 HEC-RAS Model

It is software package which notes as Hydrologic Engineering Centers in River Analysis System. It permits for users to accomplish solitary dimensional Steady flow water surface profile computation, Unsteady flow simulation, sediment transport/ mobile boundary computations and water quality analysis [30].

As stated [30] it is combined system of software, intended for interactive usage for multi-tasking atmosphere. The HEC-RAS model includes four river analysis categories: steady flow water surface profile calculation, unsteady flow simulation, movable boundary sediment transport analysis, and water quality simulation. To model one or all of this the upper four components takes similar geometric of cross sectional data and the same hydraulic calculation procedures [30].

HEC-RAS able to accomplish mobile bed sediment simulation with quasi steady flow succession data. For individually flow in time sequence flow surface profile is computed. Hydraulic variables desired for sediment processes are computed. The model simulates sediment transport capacity with different of available techniques. The sediment continuity formula is then solved in conjunction with sorting and armoring algorithms to solve for the actual volume of deposition or

erosion [28]. Latest version of HEC-RAS embraces software which known as bank stability [31] and toe erosion models BSTEM developed by the state sediment laboratory, United States Department of Agriculture (USDA), Agricultural Research Stations (ARS) [30]. The purpose of coupling HEC-RAS to BSTEM to develop the model that simulates responses between bed and bank process [32].

Governing Equation of Basic flow profile computation

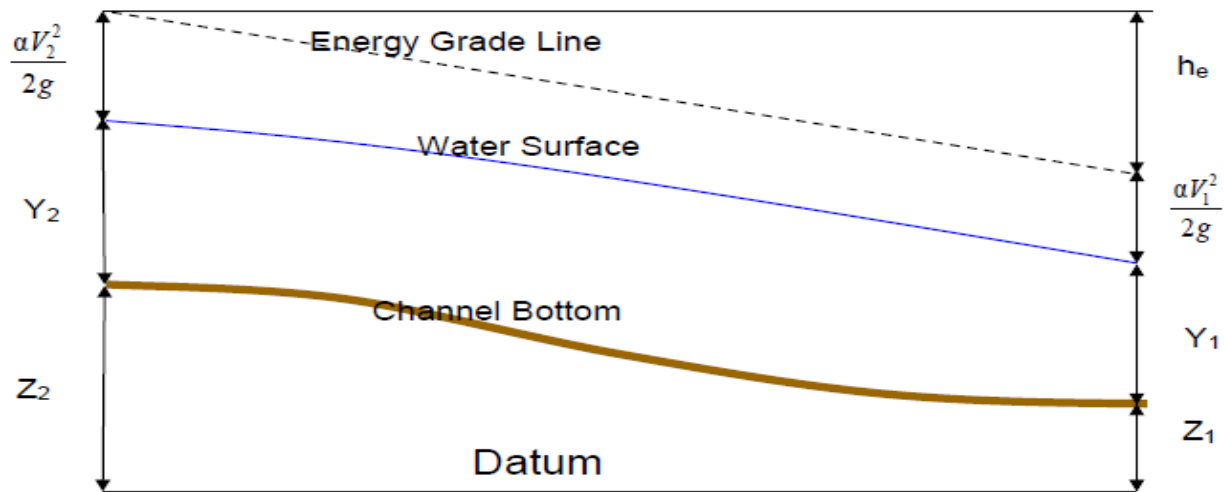


Figure 2-1 Representation of open channel flow parameters

$$H = y + z + \left(\frac{\alpha V^2}{2g}\right) \text{ Equation 2-6}$$

Where: H = energy head (m) z = base channel elevation (m) v = velocity weighting coefficient $H_1 = h_2 + h_L$

Where H1= energy head at cross section 1 (m)

h_2 = energy head at cross section 2 (m)

h_L = head loss of energy (m)

HEC-RAS latest version as stated before are able to model or simulate mobile sediment transport via selecting transport function, sorting method, fall velocity system, defining bed material gradation, including the appropriate boundary condition while for BSTEM to simulate the banks stability or failure via specifying bank failure method, ground water method and inserting BSTEM material parameters.

3 MATERIAL AND METHODOLOGY

3.1 Study Area Description

3.1.1 Location

Mersa river is found in western highlands Awash Terminal, the sub-basins of Awash basin. Mersa river originates from mountains drain to the downstream passes in Mersa town. The Mersa town is found in North Wollo, Amhara region, Ethiopia at 495 KM from Addis Ababa and Geographically located at 11°40'N latitude and 39°39.5'E longitude and 1600m elevation mean above sea level. Mersa is situated along country (Ethiopian) Highway 2 and the highway passes in Mersa river.

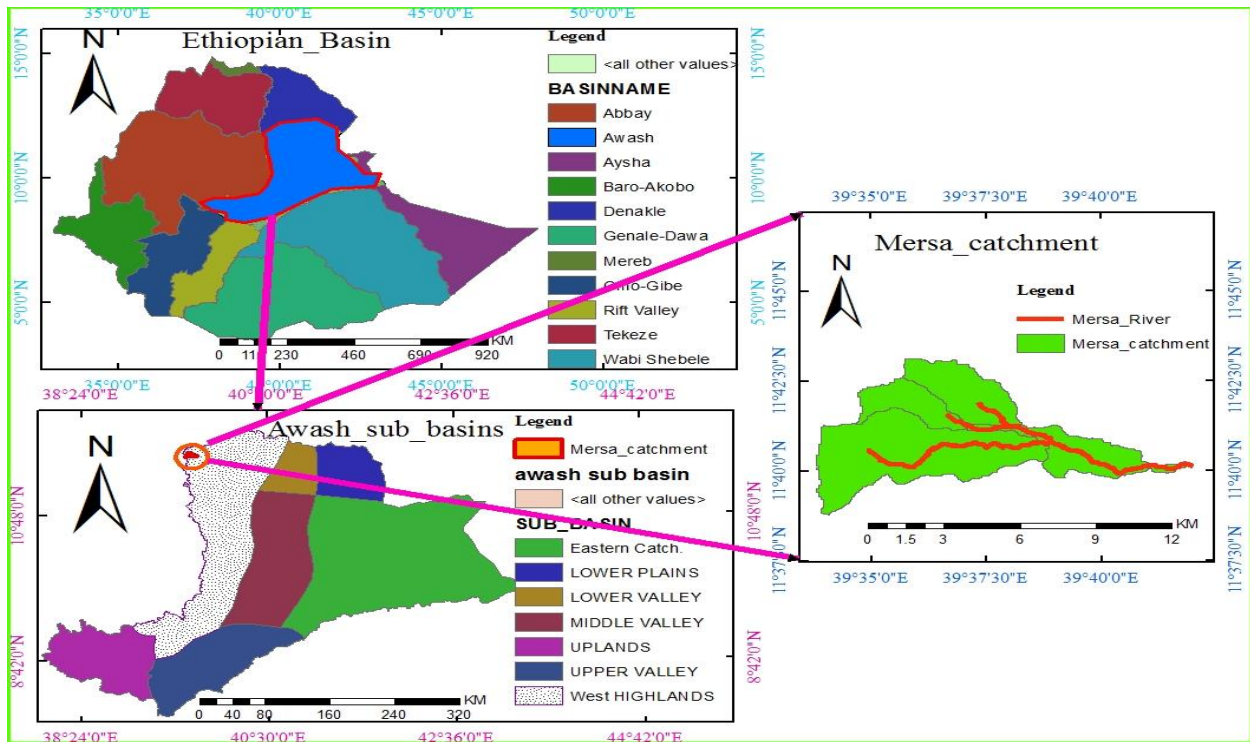


Figure 3-1 location of Mersa Catchment

The watershed is delineated using HEC-GeoHMS that is extension in Arc-GIS (for this thesis Arc-GIS 10.4 were used) with 30 m resolution of DEM (digital elevation model).

3.1.2 Soil

The earth material (soil) in Mersa catchment grounded on soil type criteria eutric cambisols, eutric regosols, leptosols and vertic cambisols are earned while according to texture sandy loam and gravel are the greatest coverage in the watershed of Mersa.

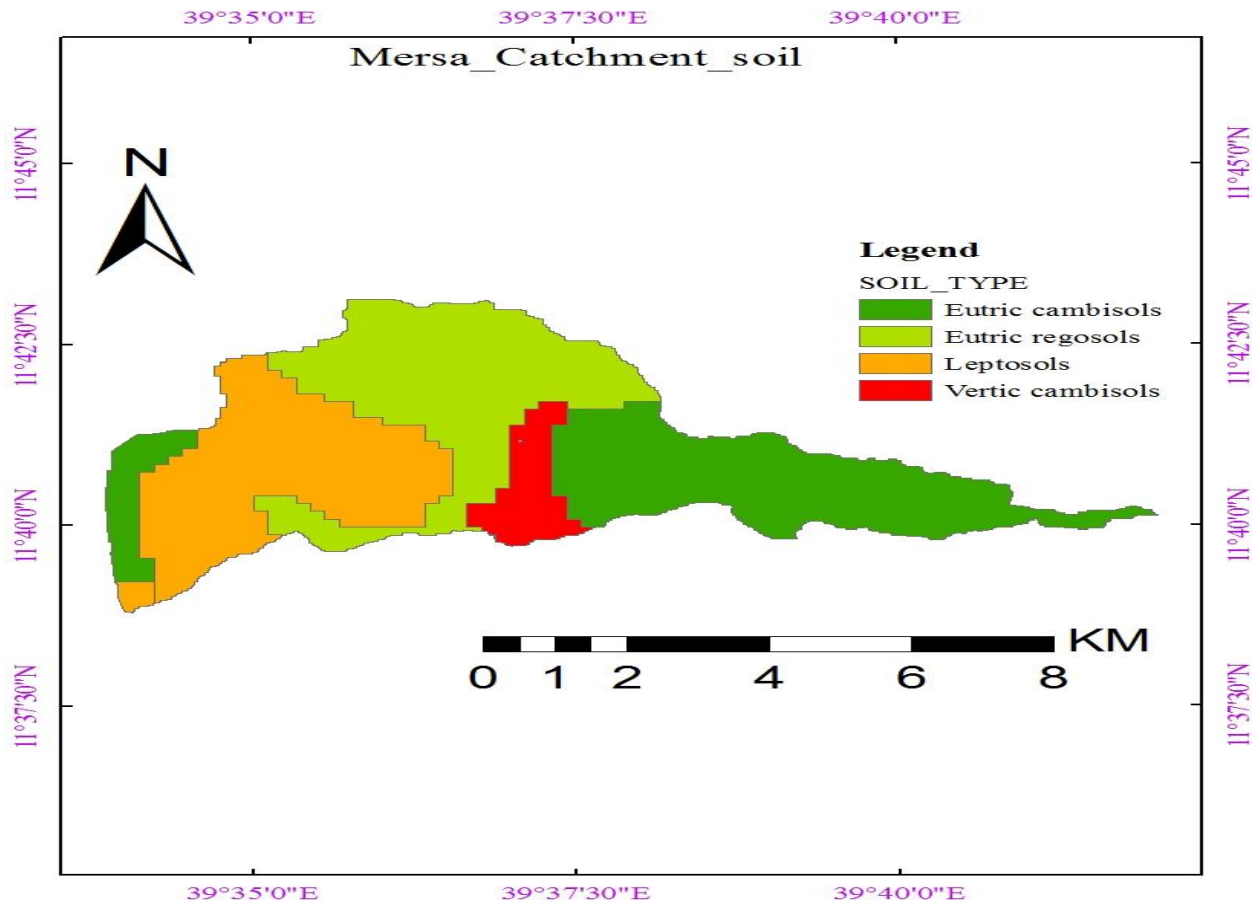


Figure 3-2 Soil map of Mersa catchment

3.1.3 Geology

Geological situation is basis and cornerstone of river stability investigation. Any stratigraphic classification of water bearing formations should begin from lithological classifications by accounting geological arrangement such alike faults, joints, folds and other tectonic features having hydrological importance³.

³ Ethiopia Health Infrastructure Program, Health Centers Groundwater Investigation Final Report February 2016

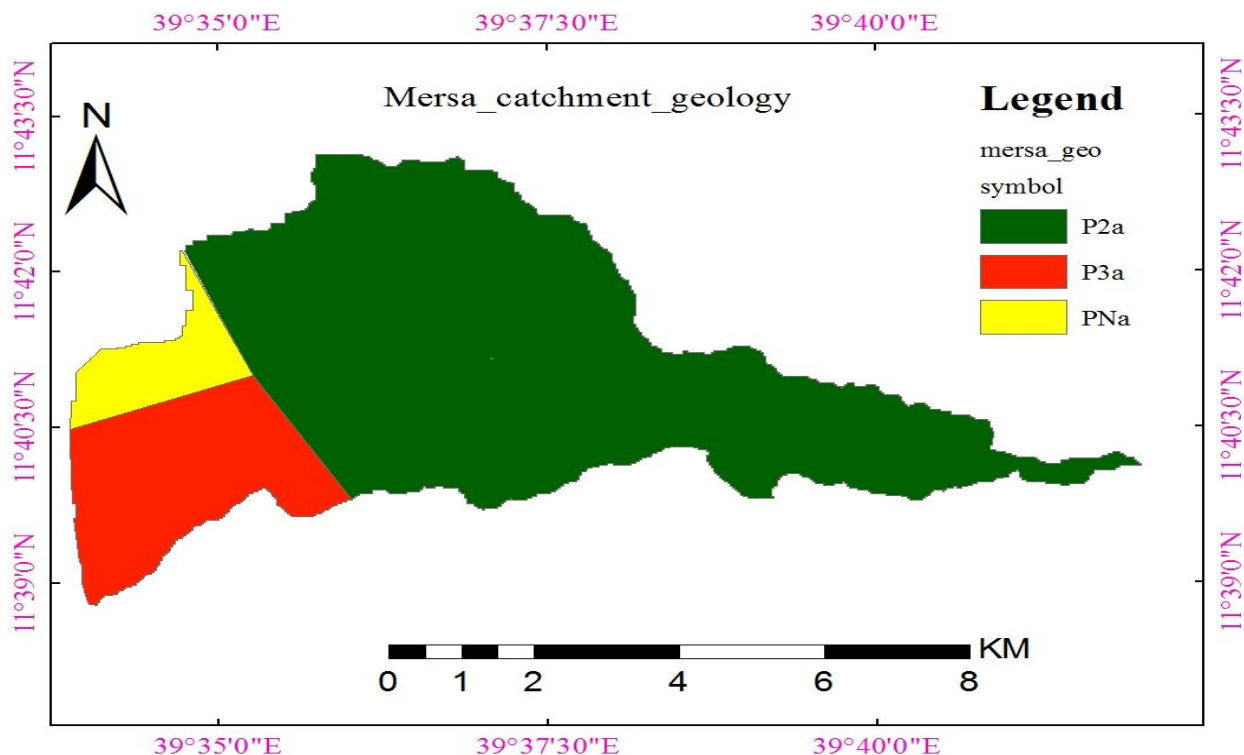


Figure 3-3 Mersa Catchment Geological Map

According to age the geological formation in the study watershed includes EOCENE, MIDDLE - LATE OLIGOCENE and OLIGOCENE - MIOCENE^{4 5} the general description of geological state of study catchment is compiled in table as follows.

Table 3-1 Geological formation of Mersa catchment

No.	Symbol	Stratigraphy	Age	Lithology	Description
1	P2a	Cenozoic Volcano	EOCENE	ASHANGI Formation	Deeply weathered alkaline and transitional basalt flows with rare intercalations of tuff, often tilted (includes Akobo Basalts of SW Ethiopia)

⁴www.ethiogrio.com/files//Ethiopia_Map_251592290.pdf

⁵ *Identification and Engineering Geological Studies of Small Hydropower Sites in Muger, Jemma And Waleka Sub-Basins (Central Ethiopia) By Nehemia Solomon*

2	P3a	Cenozoic Volcano	MIDDLE - LATE OLIGOCENE	AIBA Basalts	Flood basalts with rare basic tuff
3	PNa	Cenozoic Volcano	OLIGOCENE - MIOCENE	ALAGE Formation	Transitional and subalkaline basalts with less rhyolite with trachyte eruptive

3.1.4 Land Use and Land Cover

Land usage and coverage of land of Mersa Catchment is prepared under ArcGIS 10.4 firstly Landsat8 image from earth explorer USGS (<http://earthexplorer.usgs>) by creating account for any area desired the latest or updated image for this investigation the image released February, 27, 2019 downloaded used to composite the 11band downloaded and image classification method is unsupervised classification finally in relating the composite to the real image at google earth the land use and land cover is prepared.

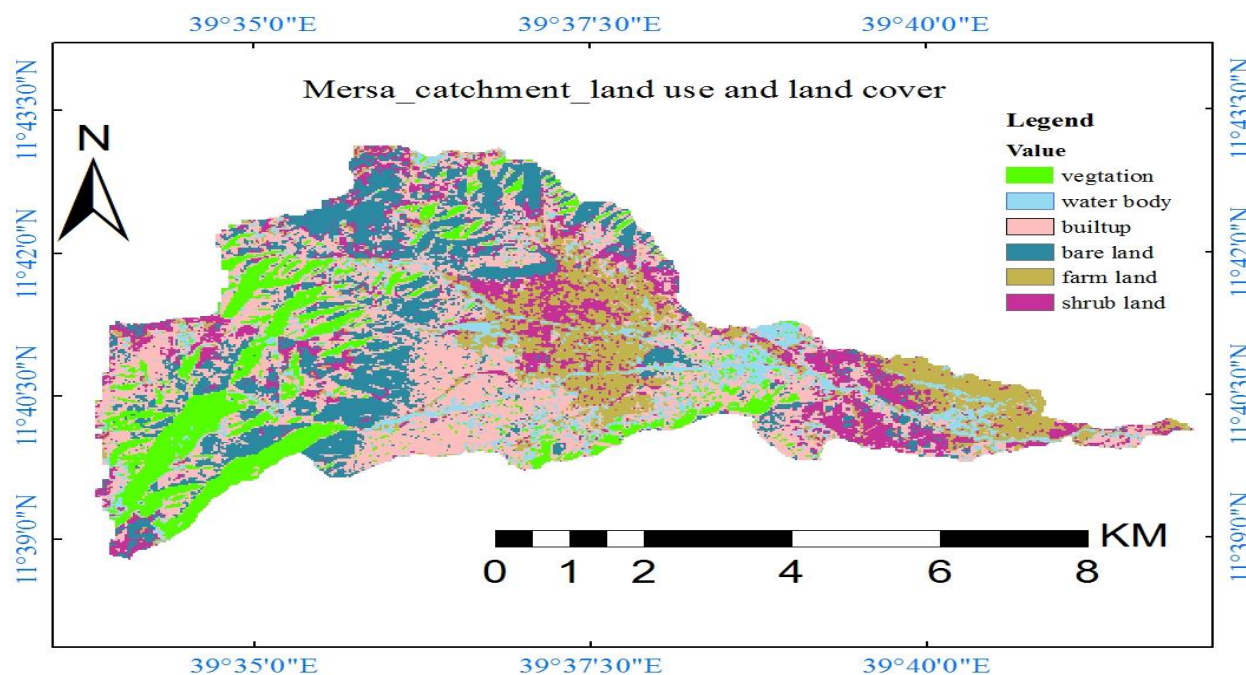


Figure 3-4 Land use and land cover of Mersa catchment

3.1.5 Climate

The minimum and maximum temperature in the catchment is 10°C and 34°C, respectively. The district receives average yearly rainfall ranging from 350–835 mm. The main rainy season is from June to end of September. The mean annual wind speed, relative humidity and solar radiation in the catchment are 2.5m/sec 0.506 and 26MJ/m² respectively.

3.2 Data Collection

3.2.1 Hydrology

The flow recorded data is collected from Minster of Water, Irrigation and Electricity for Mersa river between 1996-2012 years and the annual maximum mean daily instantaneous flow data taken to estimate the dominant and bank full discharge of the river.

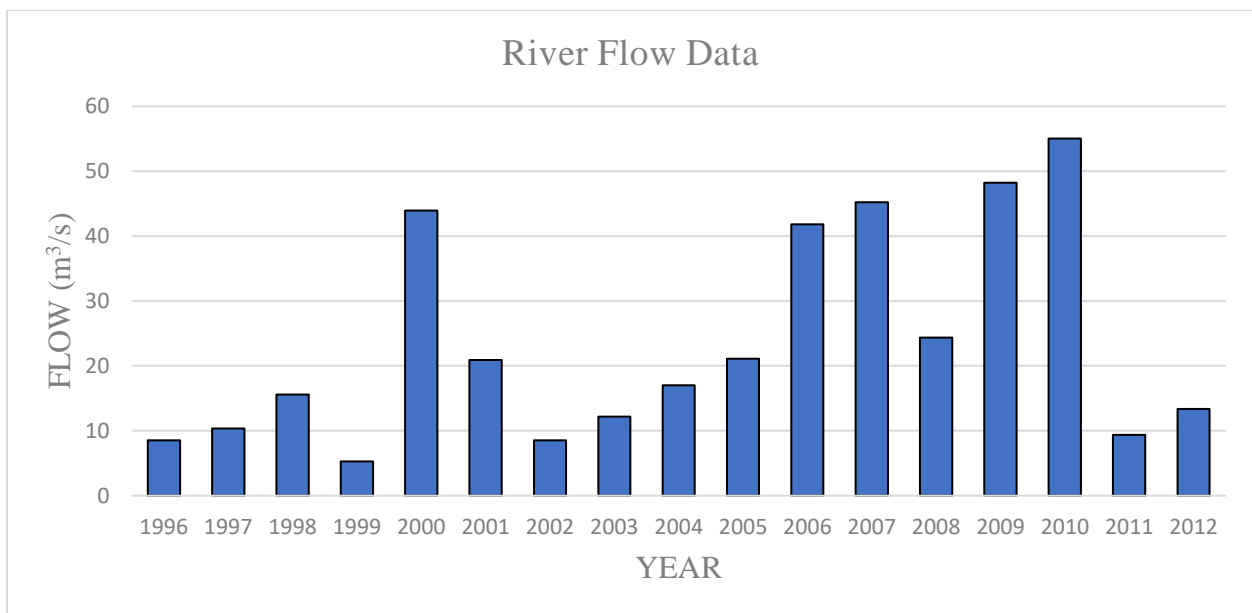


Figure 3-5 Annual maximum mean daily river flow data of Mersa River

3.2.2 Soil sample for Gradation and Triaxial Compression Test

The possible representative soil sample is taken from river bed, left side and right side bank for gradation analysis at six different places to obtain the possible accurate data regarding the soil characteristics of the selected 2.6KM channel reach so at left, right and river bed for each taken at two different place while to triaxial compression experiment sample taken from the river bank at three different places.



Figure 3-6 Soil sample taken from river bank

3.2.3 Geometric Data

3.2.3.1 River cross-section data

Channel cross section data is essential input in HEC-RAS Model so for this study 42 reach section have taken along 2.6KM the interval from 50m to 100m depend on river meandering and straightness condition.

Cross section data contain contains station number, y distance of the point from a reference point and z elevation. The downstream reach length is calculated from difference between two successive coordinate y or distance of the points.

Generally, the river of Mersa in the first two reach is narrow while begin from the 3rd station to station 26 become very wide and between station 26 and 27 there is Multi Span RC Deck Girder Bridge structure having a span length of 42.8 m, bridge opening length 22.5m and bridge width 8m. The collected cross-section data detailed shown at appendix B.



Figure 3-7 River cross section data collection using total station of at April 14, 2019

3.2.3.2 Manning roughness coefficient

Manning roughness coefficient is another basic input for HEC-RAS model setup but the challenge is earning the exact value for stream because roughness coefficient depends on channel grade of irregularity, variations of channel cross-section, relative of effective obstructions, Vegetation and meandering degree. According to [33] surface roughness coefficient value can be calculated by considering the existing channel physical characteristics such as surface roughness, vegetation, obstruction, channel alignment and channel bank and bed materials. Considering various primary variables affecting the roughness coefficient, the manning’s *n* value can be calculated by: -

$$n=(n_0+n_1+n_2+n_3+n_4) m_5 \text{ Equation..... 3-1}$$

where: n_0 = is a basic *n* value for a straight, uniform, smooth channel in the natural materials involved,[33], n_1 = is a value added to n_0 to correct for the effect of surface irregularities,[33]

n_2 =is a value for variations in shape and size of the channel cross section,[33] n_3 =is a value for obstructions,[33] n_4 =is a value for vegetation and flow conditions,[33] and m_5 = is a correction factor for meandering of channel [33].

The basic n_0 is calculated in empirical formula developed from channel bank and bed soil material that is done at sieve analysis whereas start from n_1 to m_5 estimated from table 3.2 below: -

According to [34] basic n_0 calculated by the following empirical.

$$n_0 = 0.038 * d_{90}^{1/6} \quad d \text{ in meter} \quad \text{Meyer-Peter and Muller (1948)}$$

$$n_0 = 0.039 * d_{50}^{1/6} \quad d \text{ in feet} \quad \text{Garde and Raju (1978)}$$

$$n_0 = 0.047 * d_{50}^{1/6} \quad d \text{ in meter} \quad \text{Subramanya (1982)}$$

Where d_i is a grain soil size in which i amount in percentage of material by weight finer than d .

For illustration, the Manning's roughness n , of Mersa river upstream the channel bed at station 42.

Table 3-2 Gradation result at cross section 42

Sieve size	soil laboratory gradation result
D90(mm)	8.4015
D90(m)	0.00840
D50(mm)	3.1664
D50(ft)	0.0104
D50(m)	0.0032
Garde and Raju	0.0182
Subramanya	0.0180
Meyer-Peter &Muller	0.0171
Average n_0	0.018

The other values are carefully chosen from table below

$n_1 = 0.005$, moderate degree of irregularity

$n_2 = 0.013$, channel cross-section varies occasionally

$n_3 = 0.02$, obstruction is negligible except at the bridges which will be considered separately

$n_4 = 0.007$, vegetation effect

$m = 1.00$, degree of meandering is minor.

Then, $n = (0.018 + 0.005 + 0.013 + 0.02 + 0.007) \times 1.00 = 0.065$ For the remaining channel reach manning's roughness values estimated in similar fashion as above and shown at the appendix B.

Table 3-3 Values for the computation of the roughness coefficient

Channel condition		values	
Degree of irregularity	Smooth	n1	0.000
	Minor		0.005
	Moderate		0.01
	Severe		0.02
Variations of channel cross-section	Gradual	n2	0.000
	Alternating occasionally		0.005
	Alternating frequently		0.010-0.015
Relative of effective obstructions	Negligible	n3	0.000
	Minor		0.010-0.015
	Appreciable		0.020-0.030

	Severe		0.040-0.060
Vegetation	Low	n4	0.005-0.010
	Medium		0.010-0.025
	High		0.025-0.050
	Very high		0.050-0.100
Degree of meandering	Minor	m5	1.000
	Appreciable		1.150
	Severe		1.300

3.2.3.3 Coefficients of contraction and expansion

According to [33] recommended Contraction and expansion coefficients for different channel conditions is presented in table here under: -

Table 3-4 Contraction and expansion for various channel conditions

Channel condition	Coefficient	
	Expansion	Contraction
Gradual change	0.3	0-0.1
Abrupt change	0.5	0.5

Generally, the data collected for this study broadly categorized in to primary and secondary sources summarized as shown below in table.

Table 3-5 Primary data with its sources and purposes

Data type	Data's Necessity	Data Sources
-----------	------------------	--------------

Landsat8 satellite image	To prepare land use and land cover of study area	United states geological survey (USGS) earth explorer website (http://earthexplorer.usgs)
River cross section data	Collected cross section used as geometric data input for HEC-RAS model	Field surveying using total station
Soil sample data	To classify and describe the soil type, gradation curve, soil parameter, dispersal of the soil in study reach	Field visit and take representative soil sample data
Informal interviews and questionnaires	To realize trend of the river and its both effect on the town	Peoples living around in study catchment

Table 3-6 Secondary data sources, its sources and purposes

Data type	Data's Necessity	Data sources
DEM (Digital Elevation Model)	To extract and delineate the study from total Ethiopia file catchment using GIS and HEC-GeoHMS	30m*30m resolution from MoWIE (Minster of Water, Irrigation and Electricity)
Soil shape file	To extract and describe soil kind of the study area	From MoWIE (Minster of Water, Irrigation and Electricity)
Geological shape file and map	To recognize and describe the geological property of the study area	From Ethiopia Geological Survey Mapping Agency

Metrological data (precipitation data, temperature data, wind speed, relative humidity...)	To describe that weather condition of the study area and temperature data used as one input for model	From National Metrological Agency
Hydrological data	To determine the peak discharge for several return period and used also as input	From MoWIE (Minster of Water, Irrigation and Electricity)

Table 3-7 Software and laboratory used with its purpose and source/location

Software	Purposes	Sources
Arc-GIS10.4.1 HEC-GeoHMS, HEC-GeoRAS	To prepare study area map To prepare study area soil map, geological map, land use land cover....	licensed, sources from AAU FTP portal and https://www.hec.usace
HEC-RAS	To simulate steady (water surface profile computation) and quasi-unsteady flow To simulate sediment transport simulation and BSTEM analysis	https://www.hec.usace
Laboratory test name	Purposes	Location
Sieve analysis	To determine particle size curve of sample soil taken from channel bed and channel bank	Woldia University (Civil Engineering
Triaxial compression test	To determine the soil parameters because it is input for HEC-RAS Model	Department soil laboratory)

General procedure which had followed and activity carried out is presented here under on the diagram.

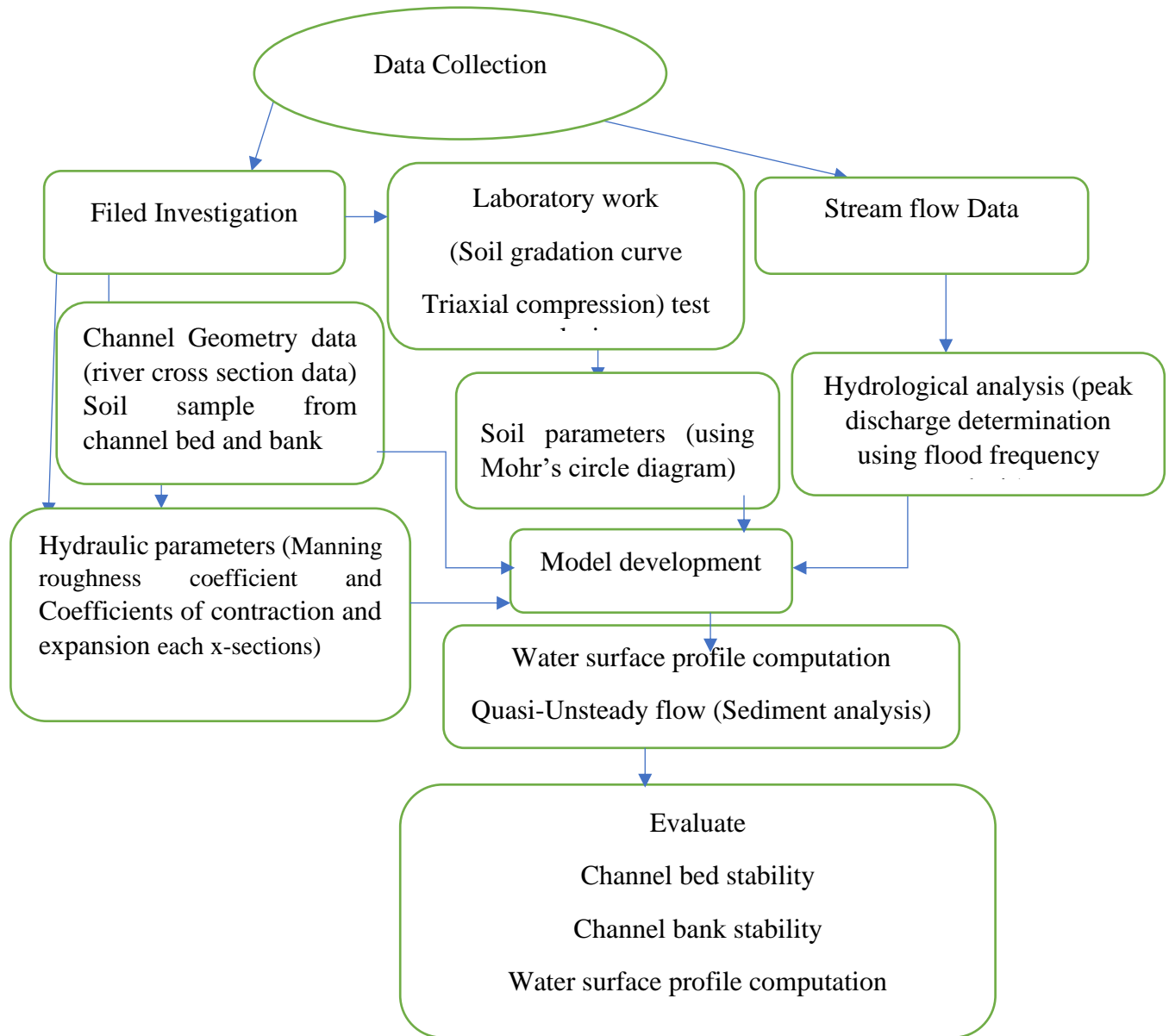


Figure 3-8 Conceptual frame work

3.3 Data Analysis

Analysis of data is essential for the future to process in model application and it is simply examining the data quality, sufficient, quantity etc. According to [35] data analysis is assessing data by means of analytical logical reasoning to examine each component of the data provided. Data analysis is the first and essential from several steps that must be carried out when conducting a research experiment. Data from several sources are collected, reviewed, and lastly analyzed to

form some sort of finding or conclusion. The most significant procedure in data examination such as outliers test and goodness of distribution fit are discussed as follows: -

3.3.1 Outlier Test

Outlier is flow data points which leave significantly from remaining data trend. The holding or removal of this outliers may meaningfully affect the degree of statistical parameters computed from the data, specifically for limited samples. Measures for treating outliers require judgment involving in mathematical and hydrologic consideration. According to [36] tests for both high and low outliers should be applied before eliminating any outliers from the data set.

3.3.1.1 Higher Outlier Test

The higher outlier can be estimated by equation: -

$Y_h = Y_m + kn * S_n$ Equation..... 3-2

Where: Y_h =Higher outlier threshold in log unit

S_n =standard deviation

Y_m =mean value

kn is chosen from table for the equivalent number of samples taken

3.3.1.2 Lower Outlier Test

The equation used to determine lower outliers

$Y_l = Y_m - kn * S_n$ Equation 3-3

Where: Y_l =Lower outlier threshold in log unit

S_n =standard deviation

Y_m =mean value

kn is read from the table for the corresponding number of samples taken (see Appendix A)

3.4 Hydrological Analysis

The maximum design flood is river peak discharges that corresponding to a certain recurrence interval which has an important in practical design of all irrigation and hydraulic structure [28].

3.4.1 Frequency Analysis of Flood

It is one method to estimate the extreme flood of the channel that is utilized to design the any hydraulic structure [28]. Flow in the watershed dependent on the characteristics of the watershed, rain fall and antecedent humidity condition individually these factors in turn bank on a list of constituent variables. this makes the estimation of the flood peak a very complex problem leading to the different approaches the empirical formula and unit hydrograph method have been described in the previous chapter. Another approach to the prediction of flood flow desired which must consider the entire catchment factors that is frequency analysis. In frequency analysis approaches, the common problem is to forecast extreme flood event. Towards the extreme, specific extreme-value distributions are supposed and the desired statistical parameter are estimated from available data through this, the flood magnitude for the specific return period is estimated.

Some of from those commonly used frequency distribution functions of the prediction of extreme flood value are described in the following session.

3.4.1.1 Gumbel’s Method

This method is introduced by Gumbel’s 1941 and commonly called Gumbel’s distribution. It is one of the most widely used probability-distribution functions for extreme value in hydrological and metrological studies for prediction of flood peak, maximum rainfall, maximum wind speed etc. Gumbel’s defined the discharge as biggest of the 365 daily flows and the annual series of the largest value of recorded flow and given by [28].

$$X_T = \bar{X} + K * \sigma n \text{ Equation..... 3-4}$$

Where: -

$$\sigma \text{standard deviation of sample of size of N: } \sigma n = \sqrt{\frac{\sum(X-\bar{X})^2}{N-1}}$$

K - Frequency factor expressed as

$$K = \frac{Y_T - Y_n}{S_n} \text{ Equation..... 3-5}$$

Y_T = reduced variant, a function of T and is given by

$$Y_T = -[\ln * \ln\left(\frac{T}{T-1}\right)] \text{ Equation..... 3-6}$$

Or $Y_T = -[0.834 + 2.303 \log * \log(\frac{T}{T-1})]$

Y_n = reduced mean, a function of sample size N and is given in standard; for $N = \infty$, $Y_n = 0.577$

S_n = reduced standard deviation, a function of sample size N and is given in table; $N = \infty$, $S_n = 1.2825$

3.4.1.2 Log-Pearson type III Distribution Method

This distribution is widely used for estimating peak discharge. In this method the variant is first transformed into logarithmic form and the transformed data is then analyzed [28]. If x variant of a random hydrologic series then the series of z variants where: -

$Z = \log x$ Equation..... 3-7

are first obtained. For this Z series, for any recurrence intervals T,

$Z_T = \bar{Z} + K_z \sigma_z$ Equation..... 3-8

Where: - K_z = a frequency factor which is a function of recurrence interval T and the coefficient of skew Ca

σ_z = standard deviation of the Z variants sample

$\sigma_z = \sqrt{(\sum(Z - \bar{Z})^2)/(N - 1)}$ Equation..... 3-9

Ca = coefficient of skew of variant z

$Ca = \frac{N \sum(Z - \bar{Z})^3}{(N-1)(N-2)(\sigma_z)^3}$ Equation..... 3-10

\bar{Z} = mean of the Z values

N= sample size = number of years of record.

$K_z = f(C_s, T)$ is given in a table

After finding Z_T the corresponding value of X_T is obtained by

$X_T = \text{antilog } Z_T$ Equation3-11

3.4.1.3 Log Normal Distribution

If the random variable $y = \log X$ is normally dispersed, then X is supposed to be lognormal distributed or in this distribution, logarithm sample is assuming to follow normal distribution. The

distribution is same as long person type III when $Ca = 0$ The other statistics or values as calculated in log-Pearson type III. So, selection of the above discussed method for this thesis is done by using l-moment ratio to differentiate which one is best fit to the data [28].

3.4.2 L-Moment Ratio Diagram

It is a diagram based on coefficient of skewness (C_s) versus coefficient of kurtosis to identify appropriate distributions. L-moment ratio diagram plotted for given regional sample size. The identification of a parent dispersion can be achieved much more easily by using L-moment ratio diagram especially for skewed distributions. Some useful relationships for constructing diagram of L-moment ratio for some common distribution are given by Hosking (1990 and 1991).

1. Uniform: $C_s = 0, C_k = 0$
2. Exponential: $C_s = 1/3, C_k = 1/6$
3. Gumbel: $C_s = 0.1699, C_k = 0.1504$
4. Logistic: $C_s = 0, C_k = 1/6$
5. Normal: $C_s = 0, C_k = 0.1226$
6. Generalised pareto: $C_k = C_s*(1+5*C_s)/(5+C_s)$ or $C_k = 0.20196C_s + 0.95924C_s^2 - 0.20096C_s^3 + 0.04061C_s^4$
7. Generalised logistic: $C_k = (1+5C_s^2)/6$ or $C_k = 0.16667 + 0.83333C_s$
8. Generalised extreme value: $C_k = 0.10701 + 0.11090C_s + 0.84838C_s^2 - 0.06669C_s^3 + 0.00567C_s^4 - 0.04208C_s^5 + 0.03768C_s^6$
9. Gamma and Pearson III: $C_k = 0.1224 + 0.30115C_s^2 + 0.95812C_s^4 - 0.57488C_s^6 + 0.19383C_s^8$
10. Lognormal: $C_k = 0.12282 + 0.77518C_s^2 + 0.12279C_s^4 - 0.13638C_s^6 + 0.11368C_s^8$
11. Wakeby lower bound: $C_k = -0.07347 + 0.14443C_s + 1.03879C_s^2 - 0.14602C_s^3 + 0.03357C_s^4$
12. Overall lower bound: $C_k = -0.25 + 1.25C_s^2$

The C_s - C_k L-moment ratio diagram for the above distribution is shown on table of in the appendix. L-Moments are linear functions of PWMS. The L-Moments are suitable because they can be straight interpreted as measures degree of probability distributions scale and shape. L-Moments are defined by Hosking in terms of the PWMs a and b as: (Hosking 1990)

$$\pi_{r+1} = (-1)^r \sum_{k=0}^r \mathbf{p} * r, k \mathbf{a} k = \sum_{k=0}^r \mathbf{p} * r, k \mathbf{b} k$$

$$\text{Where } \mathbf{p}_{r,k} = (-1)^{r-k} \binom{r}{k} \binom{r+k}{k}$$

In particular,

$$\begin{aligned}\lambda_1 &= a_0 & &= b_0 \\ \lambda_2 &= a_0 - 2a_1 & &= 2b_1 - b_0 \\ \lambda_3 &= a_0 - 6a_1 + 6a_2 & &= 6b_2 - 6b_1 + b_0 \\ \lambda_4 &= a_0 - 12a_1 + 30a_2 - 20a_3 & &= 20b_3 - 30b_2 + 12b_1 - b_0\end{aligned}$$

L-Moment ratios, which are analogous to conventional moment ratios, are given as:

$$LCV = \lambda_2 / \lambda_1$$

Where λ_1 is a measure of location

LCV = is a measure of scale and dispersion,

LCS = is measure of skewness and LCK = is a measure of kurtosis.

$$LCS = \lambda_3 / \lambda_2$$

$$LCK = \lambda_4 / \lambda_2 \quad Z_r = \lambda_r / \lambda_2, r \geq 3$$

3.5 Soil laboratory analysis

Generally, the laboratory analysis category in to two for this research i.e. the soil gradation (particle size distribution) and triaxial compression test. Both gradation curve and triaxial compression test carried out at Woldia University, Civil Engineering Department, Soil laboratory.

3.5.1 Soil Gradation Analysis

Soil gradation curve is performed to estimate the percentage of different grain sizes contained within soil. As discussed above for bed river, left bank and right channel bank of the Mersa river sample taken at 2 different places for each finally a total sample taken at six places next experimental analysis is followed and the procedure to do the grain size distribution is described as follows: -

- ✚ The soil enters oven dry for 24 hours at 115⁰C
- ✚ The sieve analysis is done, the sieve cone is arranged from large diameter to small diameter and at pan.
- ✚ The sample soil after oven dry with a known weight carefully added (to prevent loss) to the top or large sieve diameter

- ✚ Cover the sample with its cone for cover at the top Lastly shake the sieve for 10minute.

For this research the cone dimeter used start from pan, 0.075mm to 9.5mm according to [37] coarse-grained soils (size > 4.75 mm) and sand fraction ($75\mu < \text{size} < 4.75 \text{ mm}$) so, the soil retained above sieve diameter 4.75mm consider as gravel, the soil retained in between sieve diameter 0.106mm to 4.75mm considered as sand lastly the soil retained at sieve diameter 0.075mm and at the pan taken as fine soil.

3.5.2 Triaxial Compression Test Analysis

The triaxial compression test is used to determination of shear parameters in which soils under various drainage conditions. Triaxial compression test is necessary to determine the soil parameter which are affect the soil shear strength. Shear strength is the primary engineering property that controls soil mass stability under load [37]. According to [38] the shear strength parameters c is cohesion and ϕ is the angle of shearing resistance of soils either in the undisturbed or remolded states. For this research the disturbed soil was taken from the Mersa reach and remolded at the laboratory. The soil sample taken at 3 different places from river bank for triaxial compression test and experimental procedures are: -

- ✚ The soil sample were remolded in such a way that as seen in the figure here under
- ✚ Then the remolded sample inserted to a triaxial cell
- ✚ proper adjustments have been made so that the piston of the triaxial cell just rests on the top platen of the specimen
- ✚ Chamber of the triaxial cell filled with water. A hydrostatic pressure $\delta 3$ were applied to the specimen through the chamber fluid.
- ✚ proper contact between the piston and the top platen on the specimen were checked.
- ✚ Take initial proving ring dial readings for vertical compression intervals of 0.254 mm.
- ✚ Finally, the load applied and the failure point is shown on the computer and generate the result from software to excel.



Figure 3-9 Doing Triaxial compression test at Woldia University

3.6 HEC-RAS Model Development

As discussed earlier in the previous chapter HEC-RAS allows for users in order to do one dimensional Steady flow to water flow surface profile computation, Unsteady flow simulation, Quasi-unsteady sediment transport/ mobile boundary computations and water quality analysis [30]. For this study the model is developed 1D HEC-RAS model to compute sediment transport capacity, to predict the riverbed change by using sediment balance equations and to assess the water surface profile.

3.6.1 Steady Flow Analysis and Flood Inundation Map

3.6.1.1 Steady flow simulation

Energy equation is used for computing the water flow surface profile. That is solved by iterative procedure, which is called direct standard step method from one cross section to the other cross

section [30]. The model also using manning equation to compute water discharge [30]. The equation is presented as follows for both computing water surface profile and manning equation respectively.

$$Z_2 + Z_1 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \dots\dots\dots 3-12$$

Where: -

Z_1, Z_2 = Bed elevation of the channel at section 1 and 2 respectively (m)

Y_1, Y_2 = Water depth at section 1 and 2 respectively (m)

V_1, V_2 = average or mean velocity at section 1 and 2 respectively (m/s)

α_1, α_2 = velocity weighing/allowance coefficient at section 1 and 2 respectively (dimensionless)

h_e = energy head loss b/n section 1 and 2 (m), which is comprise of frictional loss and contraction/expansion

$$Q = \frac{A}{n} * R^{2/3} * S f^{1/2} \dots\dots\dots 3-13$$

Where: - Q = water discharge (m^3/s)

A = area cross section (m^2)

R = hydraulic radius (m)

n = manning roughness coefficients

The surveyed cross section collected data used to establish 1D Steady flow Model for different discharge scenarios to analyze the water level in all reach.

The discharge computed by GEV is used for upstream boundary and the downstream boundary condition the normal depth which is determined from longitudinal slope of the river reach. The discharge used in steady flow analysis is shown in table below with return period 2 to 100 year.

Table 3-8 Steady flow upstream boundary conditions

Return period (year)	Discharge (m^3/s)
	upstream boundary condition

2	41
10	68
50	91
100	101

3.6.1.2 Flood Plain Delineation

Flood inundation map is prepared using both HEC-RAS and HEC-GeoRAS (Arc-GIS extension) and the following sequential step is followed to get flood plain map.

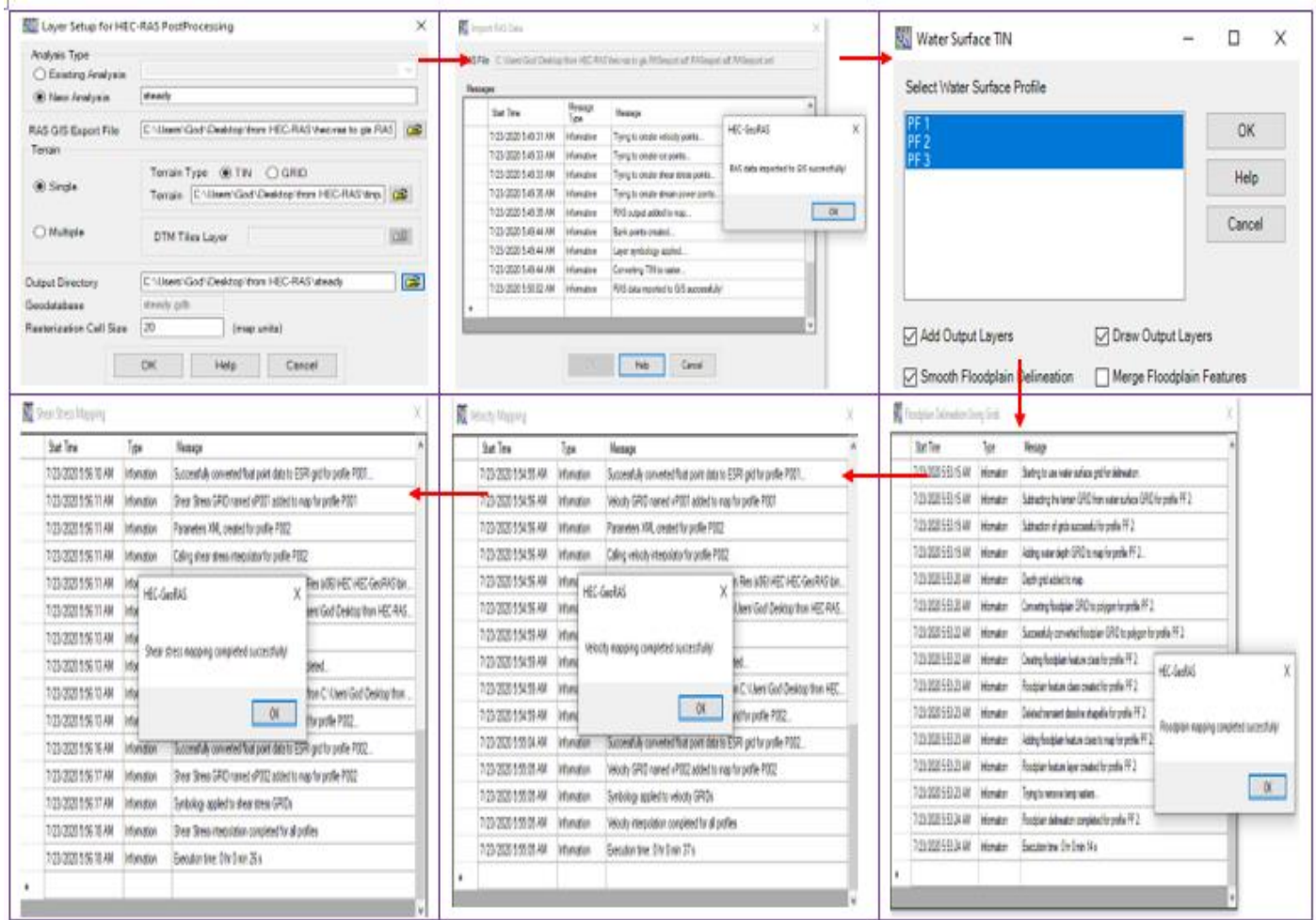


Figure 3-10 Floodplain map preparation process in Arc-map (HEC-GeoRAS)

As shown in the figure 3.10 the steps to prepare flood inundation map and procedures are: -

- ✚ The result of steady flow from HEC-RAS exported to GIS
- ✚ In ARC map the exported SDF to XML file
- ✚ Import changed (XML file) RAS data
- ✚ Inundation mapping (water surface generation and flood plain delineation using raster)
- ✚ Velocity mapping
- ✚ Shear stress mapping

3.6.2 Sediment Transport Computations

To simulate the sediment analysis or river bed change of the channel quasi-unsteady flow is used. Because its capabilities are unique to sediment transport analysis and simulate the flow series by assuming approximate continuous hydrograph (histograms) with a sequence of steady flow computations in corresponding flow durations [30]. From 17-year recorded flow data, the 7-year daily flow events which start from 01 January 2006 to 31 December 2012 is used for this study to modeled simulation of sediment the annual hydrograph selected is discretized to a series of daily flow. Daily discretized flow records and daily temperature is required in quasi-unsteady sediment transport analysis for this study 7-year daily flow events out of 17-year recorded flow data and 7 year average daily temperature of Mersa are used for analyze start from 01 January 2006 to 31 December 2012 additionally hydrograph data of both daily discharge and average daily temperature is presented as follows respectively.

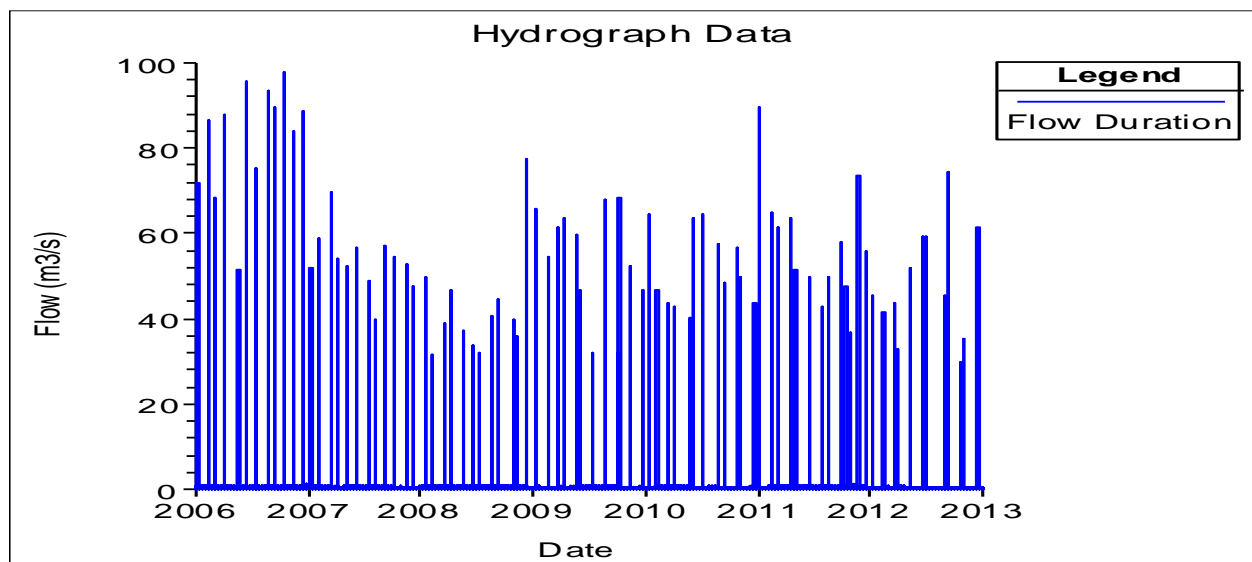


Figure 3-11 7year Quasi-Unsteady daily flow data series

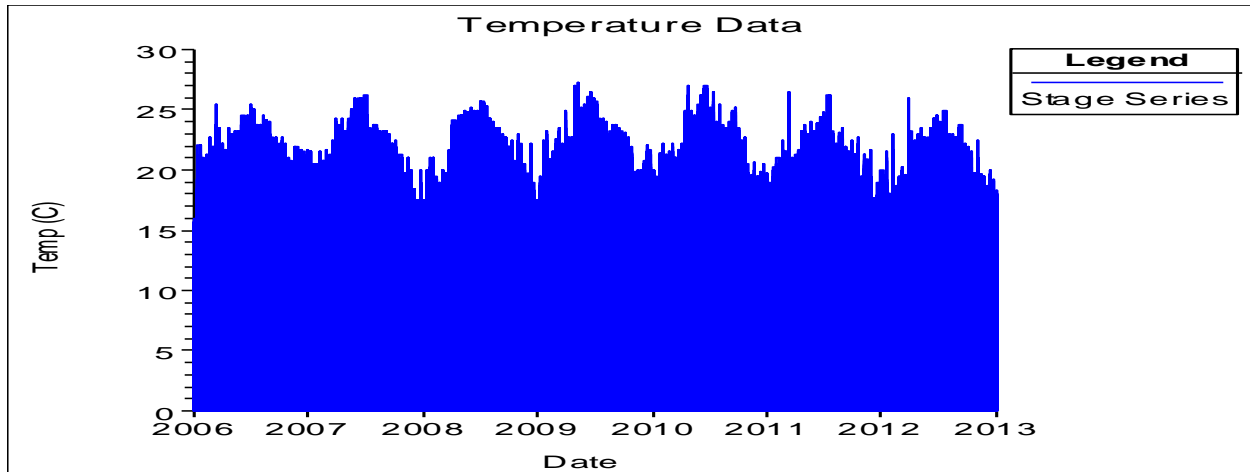


Figure 3-12 7year Quasi-Unsteady average daily temperature

3.6.3 Bank Stability and Toe Erosion Model (BSTEM) Analysis

The river bank failure clearly lead to life and property loss. According to [37] it is essential to check channel stability through a recent soil testing method and stability analysis. In this study as discussed earlier soil sample taken from the bank for triaxial compression test, to determine soil parameters and BSTEM is used for stability analysis. Bank stability and toe erosion model are bank failure analysis depend on fundamental force stability, with a toe scour model that allows response between the hydraulic hydrodynamics on the bank toe which could exacerbate the failure risk during toe scour or decrease failure risk during toe protection [32]. The aims of HEC-RAS with BSTEM are to construct the model that simulates responses between river bank and bed process. BSTEM input data are all the data which were used in the sediment analysis and additionally the right and left edge and toe station, selection of corresponding bank failure method and ground water method and BSTEM layer parameters or soil parameter (c & ϕ) are required. In this thesis the method of bank failure is slice method because it is more conventional geotechnical to planer failure and ensures that force and momentum balance calculated to individual segment of failure plane, closer to comparable geotechnical analysis and computes a more realistic distribution along the failure plane [32].The ground water elevation for BSTEM taken as 200m below ground surface these data is obtained from AWWDS the average ground water elevation in the study area.

4 RESULT AND DISCUSSION

4.1 Data Analysis

It is evaluating the data quality, sufficient or quantity for this investigate 17 year from 1996 up to 2012 river gauged data is analyzed its outlier test and goodness of distribution fit to compute discharge with different return period because it is key input for the HEC-RAS steady flow model.

4.1.1 Outlier Test Result

The outlier test is compulsory before the data used for other advanced hydrological analysis because it affects the data quality and here for 17year stream gauged data done for both high outlier and lower outlier test.

4.1.1.1 Higher Outlier Test Result

$$Y_h = Y_m + kn * S_n = 1.61 + 2.309 * 0.149 = 1.954, Y_h = 10^{1.954} = 89.958$$

The maximum flow data at year of 2006 which is less than that of threshold value.

Hence, $89.958 \text{ m}^3/\text{s} > 82.1 \text{ m}^3/\text{s}$, or $1.954 > 1.914$ it is ok! all the value is less or smaller than the high outlier threshold value, therefore here are no high outliers in from sample.

4.1.1.2 Lower Outlier Test Result

$$Y_l = Y_m + kn * S_n = 1.61 - 2.309 * 0.149 = 1.266 Y_l = 10^{1.266} = 18.448$$

The lowest stream flow data in the year 1999 which is greater than the threshold value of lower outliers i.e. $18.448 \text{ m}^3/\text{s} < 18.72 \text{ m}^3/\text{s}$, or $1.266 < 1.272$ it is ok!

Generally, for 17year sample stream flow data of Mersa river analyzed at this study there no high outlier and low outlier (see appendix A).

4.2 Hydrological Analysis Result

The 17 successive year stream gauged data are analyzed for outlier test next the peak flood for different return period would be computed as follows but before this to which method of frequency flood analysis the recorded is fitted must be carried out primarily using l-moment ratio diagram. The detailed calculation for each frequency analysis method such as Gumbel's, Long-Pearson type III distribution and Log normal distribution see appendix A.

4.2.1 Best Fit Distribution

From L-Moment ratio diagram analysis as shown below the stream gauged data collected best fit to General extreme value (Gumbel’s Method).

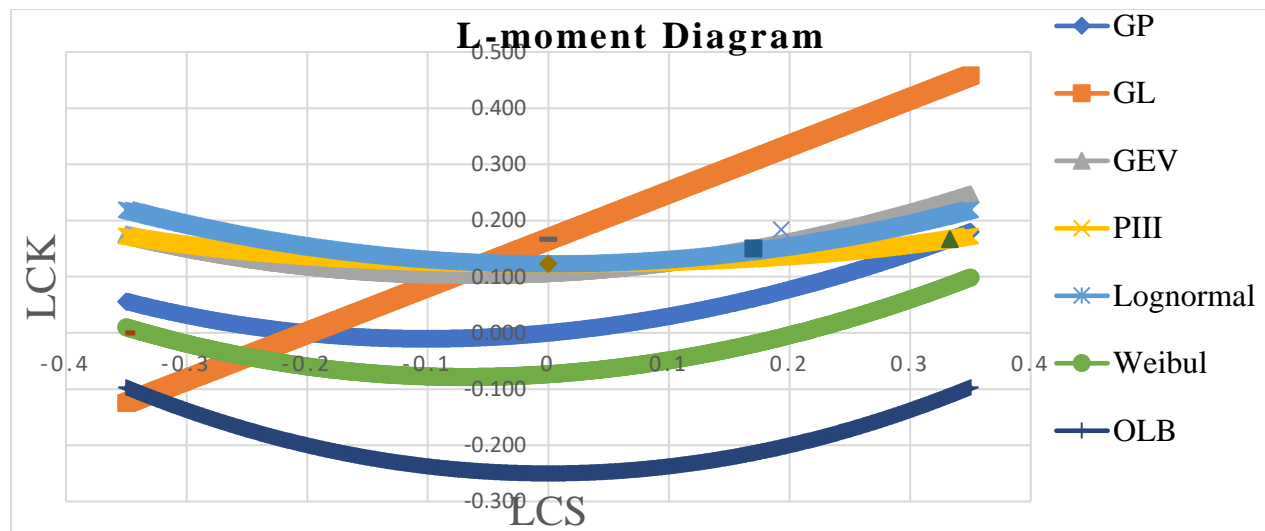


Figure 4-1 L-moment Ratio Diagram

4.2.2 Peak Discharge Computation

The peak flood estimation is computed by Gumbel method (general extreme value) as a result of recorded data gathered is close-fitting to Gumbel method. So, the discharge flow is computed for 2year, 10year,50 year and 100year using General Extreme Value as shown in table below and the complete calculation is found at appendix A.

Table 4-1 Peak discharge for different return period

Return period (T)	2	10	50	100
Y_T	0.367	2.250	3.902	4.600
k	-0.146	1.664	3.250	3.921
X_T (m ³ /s) or Q	41	68	91	101

4.3 Soil sample Experimental Analysis

4.3.1 Particle Size Distribution Curve Sieve Analysis

Laboratory result of sieve analysis were grouped under two broad classes such as analysis for river bank and river bed material. Gradation curve of soil done for six representative soil sample that

have taken from different places and then to know the proportion of gravel, sand and fine part of the soil material. The study channel reach has two parts that are upper reach and lower reach so the sample were taken at upper three for left river bank, right river bank and river bed soil and on the same way from lower channel reach also taken.

1. River bed material composition

The gradation curve analysis result of bed material composition characterized by coarse-grained including sand and gravel we can see that the bed material above 95% total sample were coarser with particle grain size greater than 0.075mm.

Table 4-2 Upper reach river bed material particle size curve analysis

sieve No.	sieve diameter	mass of empty sieve (g)	mass of sieve + Soil retained (g)	soil retained (g)	mass cumulative retained (g)	percent retained (%)
	9.5	495.8	495.8	0	0	0
4	4.75	460.5	698.5	238	238	43.24
10	2	402.6	467.2	64.6	302.6	54.99
20	0.84	386.5	445.3	58.8	361.4	65.66
40	0.425	391.6	455.6	64	425.4	77.29
60	0.25	384.1	447.7	63.6	489	88.84
140	0.106	363.5	398.2	34.7	523.7	95.15
200	0.075	357.5	371.1	13.6	537.3	97.62
pan		352.6	365.7	13.1	550.4	100
total				550.4		

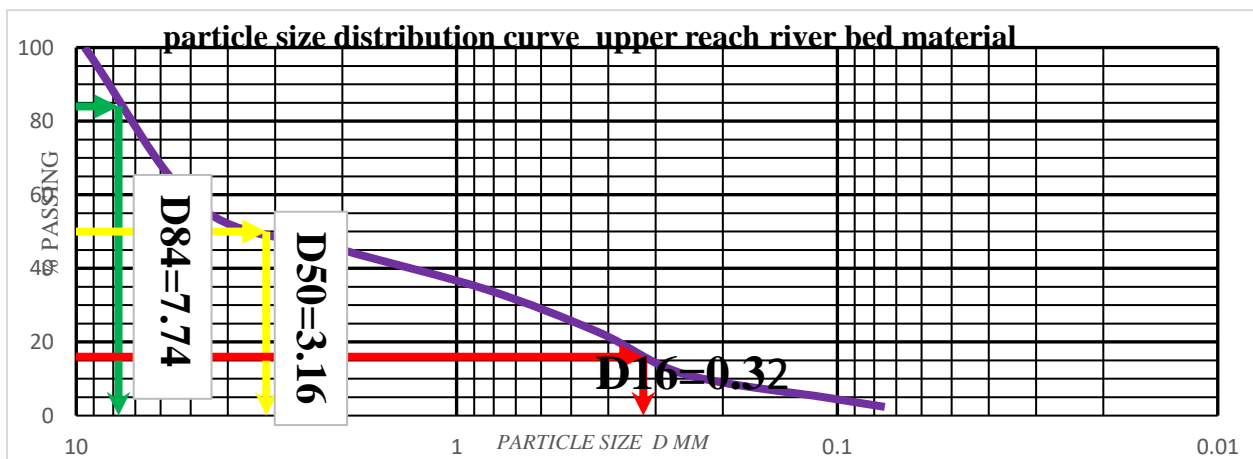


Figure 4-2 Grain size distribution curve upper reach river bed material

As shown in both table and graph above the soil particle @ upper reach of Mersa river bed soil material the percentage of Gravel, sand and fine soil material is 43.23 with particle size larger than 4.75mm, 54.39 with particle grain size in the range between 0.075mm to 4.75mm and 2.38 with particle size less than 0.075mm respectively and shows that more than 95% of bed material is Gravel and sand. D84, D50, and D16 indicates particle size valued as 7.74,3.16 and 0.32 at which 84%,50% and16% of the soil materials are finer than this size. In the same method the gradation curve result for lower channel reach of bed sediment composition showed that again coarse-grained soil dominated by sand (fine sand to very coarse sand) and gravel (from very fine gravel to medium gravel). Uniformity coefficient (D60/D10) for both upstream and lower reach were 23 and 14 respectively for sand and gravel which had uniformity coefficient greater than 6 for sand and 4 for gravel show that a well graded coarse-grained soil. Furthermore, the table and the gradation curve of lower reach bed material shown in appendix C.

2. River bank material composition

The laboratory result river bank material for both left and right corresponding to upper reach and lower reach dominated by coarse grained material this is good that the bank not affected by erosion during dry season where as in the rainy period infiltration capacity is small and that cause to soil mass loss because of saturation the bank become fail to bed of the channel. The upper reach right river bank material table and gradation curve shown below and the remaining were placed at appendix C.

Table 4-3 Upper reach right river bank material particle size curve analysis

sieve No.	sieve diameter	mass of empty sieve (g)	mass of sieve + Soil retained (g)	soil retained (g)	mass cumulative retained (g)	percent retained (%)
	9.5	495.8	495.8	0	0	0
4	4.75	460.5	741.4	280.9	280.9	51.33
10	2	402.6	509.6	107	387.9	70.89
20	0.84	386.5	450.6	64.1	452	82.60
40	0.425	391.6	437.4	45.8	497.8	90.97
60	0.25	384.1	410	25.9	523.7	95.71
140	0.106	363.5	376	12.5	536.2	97.99
200	0.075	357.5	364.6	7.1	543.3	99.29
pan		352.6	356.5	3.9	547.2	100
total				547.2		

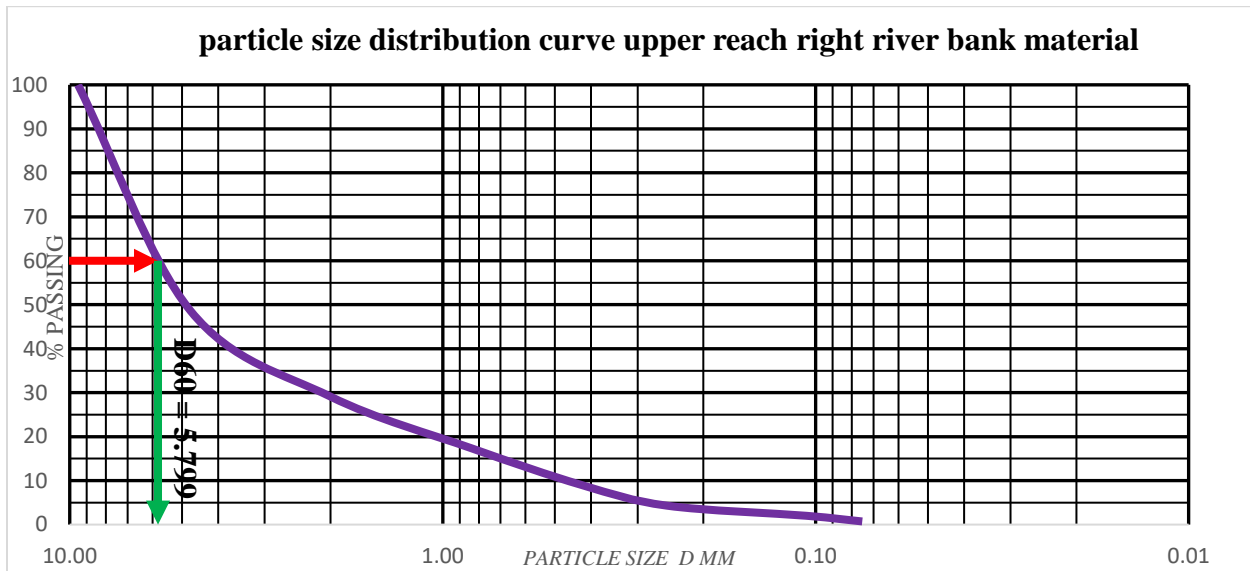


Figure 4-3 Grain size distribution curve upper reach right river bank material

As shown in the above graph and table the proportion of right river bank material at upper reach include an insignificant amount of fine to large coarser-grained soil in detail fine 1%, sand 48% and 51% gravel. The D60 particle size calculated 5.8mm at which 60% of soil material is finer than this size.

4.3.2 BSTEM Material Parameters

Soil parameter cohesion c and angle of internal friction ϕ are essential input for BSTEM model that should be determined in laboratory. As defined earlier triaxial compression test is to determine the soil parameter or variables (c and ϕ). Specifically, for these study triaxial compressions test done for river bank soil sample and under 50KN, 100KN and 200KN load condition. Even though the experiment (triaxial compression test) carried out not adequate to determine the soil strength parameter but also it requires Mohr’s circle analysis having these experiment result. According to [37] Mohr’s circle is a diagram or graphical technique for the estimation of stresses on a plane inclined to the principal planes. By drawing the Mohr’s circle, the three-test result in a single graph as presented below soil shear strength variables or parameter become cohesion, $C=5.46\text{KPa}$ and shearing resistance angle, $\phi=14^{\circ}$

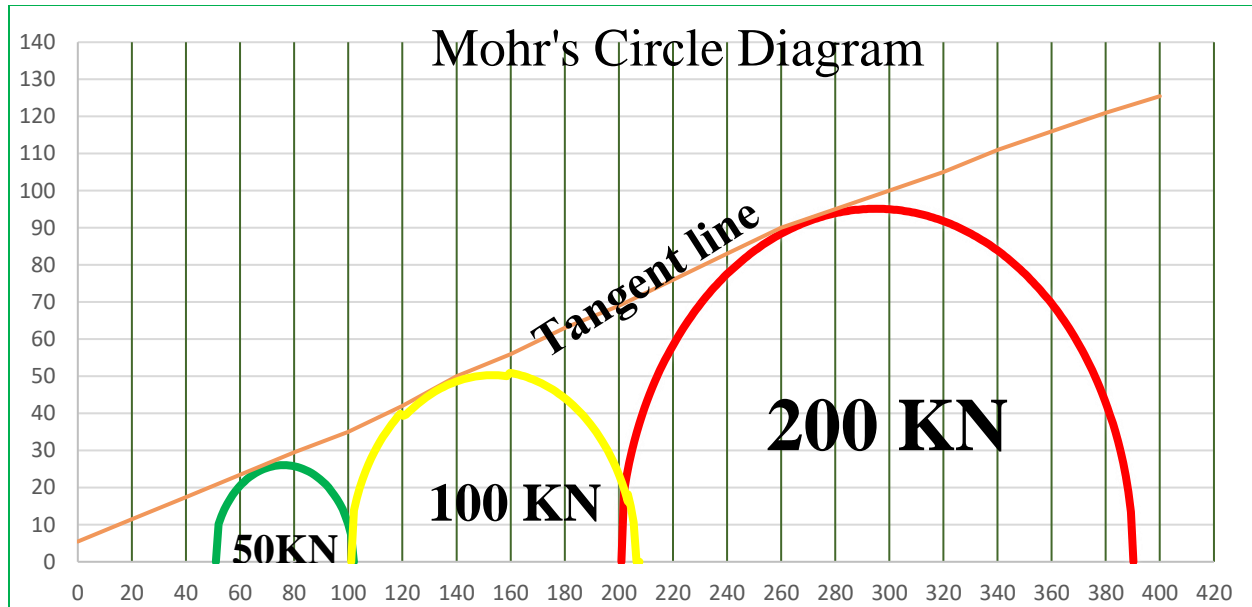


Figure 4-4 Mohr's circle diagram for different axial load (50KN, 100KN and 200KN)

4.4 Channel Stability Evaluation

Channel stability can be evaluated by assessing the channel bed change, channel bank variation and water surface profile for different recurrence interval to check its effect over the neighboring area. Thus, evaluation system is described one by one clearly in the next session.

4.4.1 Channel Bed Stability Analysis

There were different methods to simulate the sediment transport. This selection based on soil composition of the study watershed or catchment. In this study Meyer Peter Muller and Yang for sediment transport simulation model used with 7year daily flow and temperature data. In the HEC-RAS manual for sand and gravel soil material, Yang and Meyer Peter Muller transport function is recommended. The simulation result shows that together aggradations and degradation were observed along Mersa river reach. Channel bed change of Mersa river checked by two ways one evaluating the vertical bed change and the remaining is assessing the quantity of sediment entry with sediment leaving.

4.4.1.1 Vertical Channel Bed Change

Vertical channel bed change simply indicates the amount of erosion or deposition in depth. According to Yang sediment transport formula aggradation and degradation simulated result for

7year daily discharge of Mersa river reach tabulated and plotted as follows. As we can see in the figure below (Figure 4-5) the maximum deposition 2.23m at station 28 and the extreme degradation 2m at station 7 was observed. The average degradation 1.31m and average aggradation 1.09m was recorded so the outcomes shows that the degradation pattern somewhat greater than aggradation in Mersa river reach.

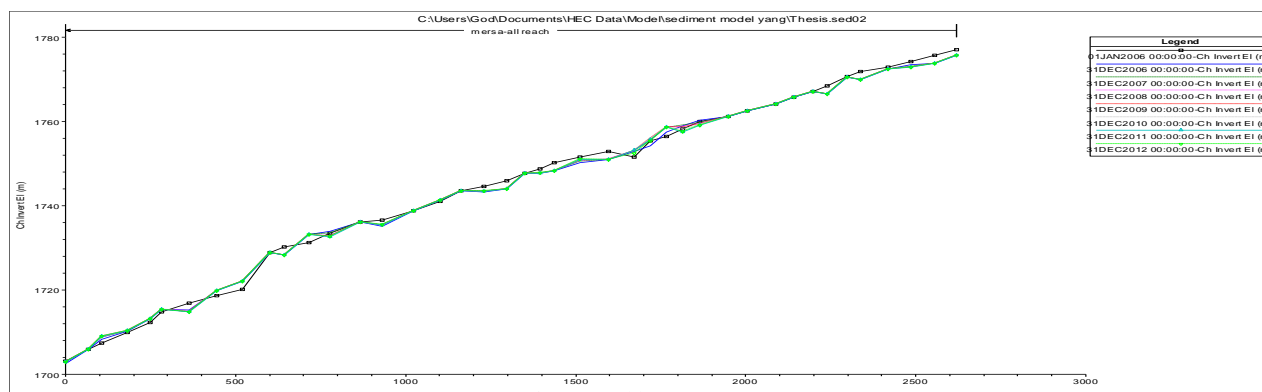


Figure 4-5 Sediment spatial plot Yang

As presented under table 4-4 below even if aggradation and degradation was observed some cross section also neither aggrade nor degrade in such station 31,32,33.... can be mentioned by Yang sediment transport method.

Table 4-4 Channel Bed elevation change according to Yang

No.	River	Reach	RS	Elevation (m) @Jan, 1, 2006	Elevation (m) @Dec,31,2012	Difference (m)
1	Mersa	all reach	42	1776.981	1775.675	-1.31
2	Mersa	all reach	41	1775.755	1773.759	-2.00
3	Mersa	all reach	40	1774.207	1772.916	-1.29
4	Mersa	all reach	39	1772.954	1772.444	-0.51
5	Mersa	all reach	38	1771.871	1769.874	-2.00
6	Mersa	all reach	37	1770.617	1770.581	-0.04
7	Mersa	all reach	36	1768.513	1766.514	-2.00
8	Mersa	all reach	35	1767.059	1767.059	0.00
9	Mersa	all reach	34	1765.785	1765.785	0.00
10	Mersa	all reach	33	1764.21	1764.21	0.00
11	Mersa	all reach	32	1762.539	1762.539	0.00
12	Mersa	all reach	31	1761.182	1761.182	0.00
13	Mersa	all reach	30	1759.98	1759.146	-0.83

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14	Mersa	all reach	29	1758.247	1757.622	-0.62
15	Mersa	all reach	28	1756.402	1758.631	2.23
16	Mersa	all reach	27	1755.367	1755.377	0.01
17	Mersa	all reach	26	1751.532	1752.479	0.95
18	Mersa	all reach	25	1752.921	1750.922	-2.00
19	Mersa	all reach	24	1751.589	1751.097	-0.49
20	Mersa	all reach	23	1750.289	1748.29	-2.00
21	Mersa	all reach	22	1748.751	1747.794	-0.96
22	Mersa	all reach	21	1747.705	1747.705	0.00
23	Mersa	all reach	20	1745.997	1743.999	-2.00
24	Mersa	all reach	19	1744.521	1743.486	-1.04
25	Mersa	all reach	18	1743.531	1743.531	0.00
26	Mersa	all reach	17	1741.037	1741.285	0.25
27	Mersa	all reach	16	1738.831	1738.831	0.00
28	Mersa	all reach	15	1736.616	1735.484	-1.13
29	Mersa	all reach	14	1736.084	1736.084	0.00
30	Mersa	all reach	13	1733.537	1732.767	-0.77
31	Mersa	all reach	12	1731.328	1733.126	1.80
32	Mersa	all reach	11	1730.245	1728.246	-2.00
33	Mersa	all reach	10	1728.954	1728.954	0.00
34	Mersa	all reach	9	1720.103	1722.112	2.01
35	Mersa	all reach	8	1718.622	1719.835	1.21
36	Mersa	all reach	7	1716.877	1714.877	-2.00
37	Mersa	all reach	6	1714.803	1715.432	0.63
38	Mersa	all reach	5	1712.324	1713.181	0.86
39	Mersa	all reach	4	1709.991	1710.383	0.39
40	Mersa	all reach	3	1707.437	1709.068	1.63
41	Mersa	all reach	2	1705.965	1705.965	0.00
42	Mersa	all reach	1	1703.185	1703.027	-0.16

Generally Yang’s transport method result could be grouped under the 3 category one there were no aggrade or degrade from both banks but deposition or erosion observed in channel bed, second no aggrade or degrade at the left and right bank including channel bed was observed and the remaining aggrade or degrade observed at right and left bank in addition to channel bed.

As shown below in the figure 4-6 there were no aggradation and degradation or erosion in the river bank whereas the degradation was observed at channel bed only. In the same fashion at station 38 figure 4-7 degradation were observed and that is acceptable.

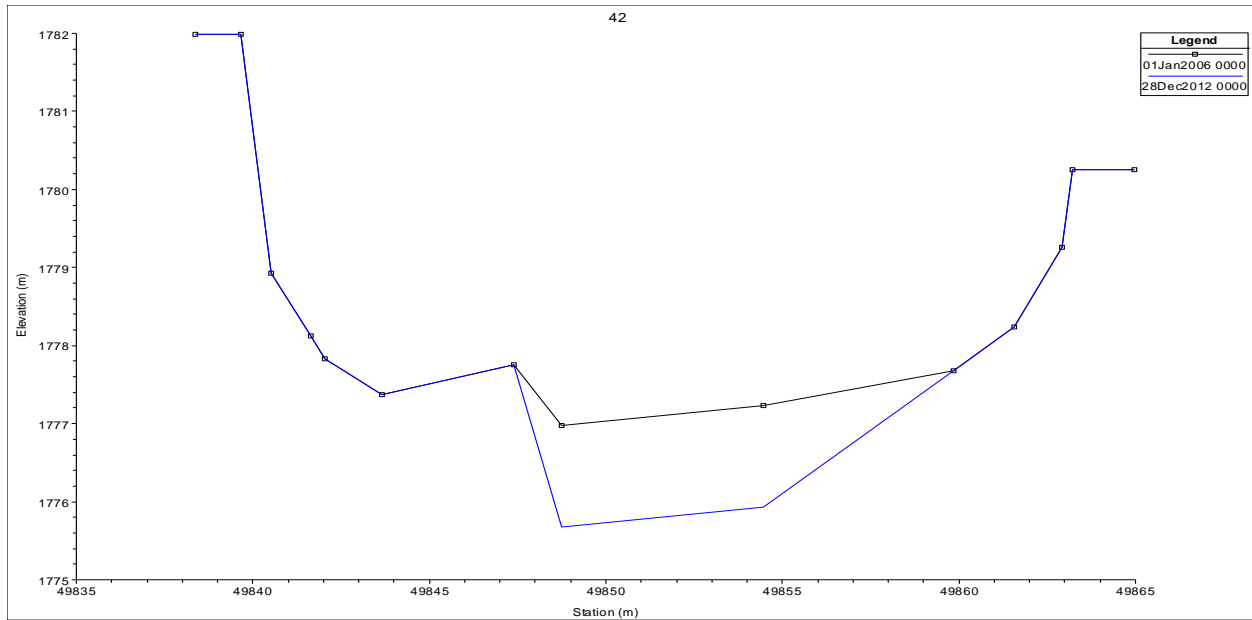


Figure 4-6 Sediment cross section change at station 42

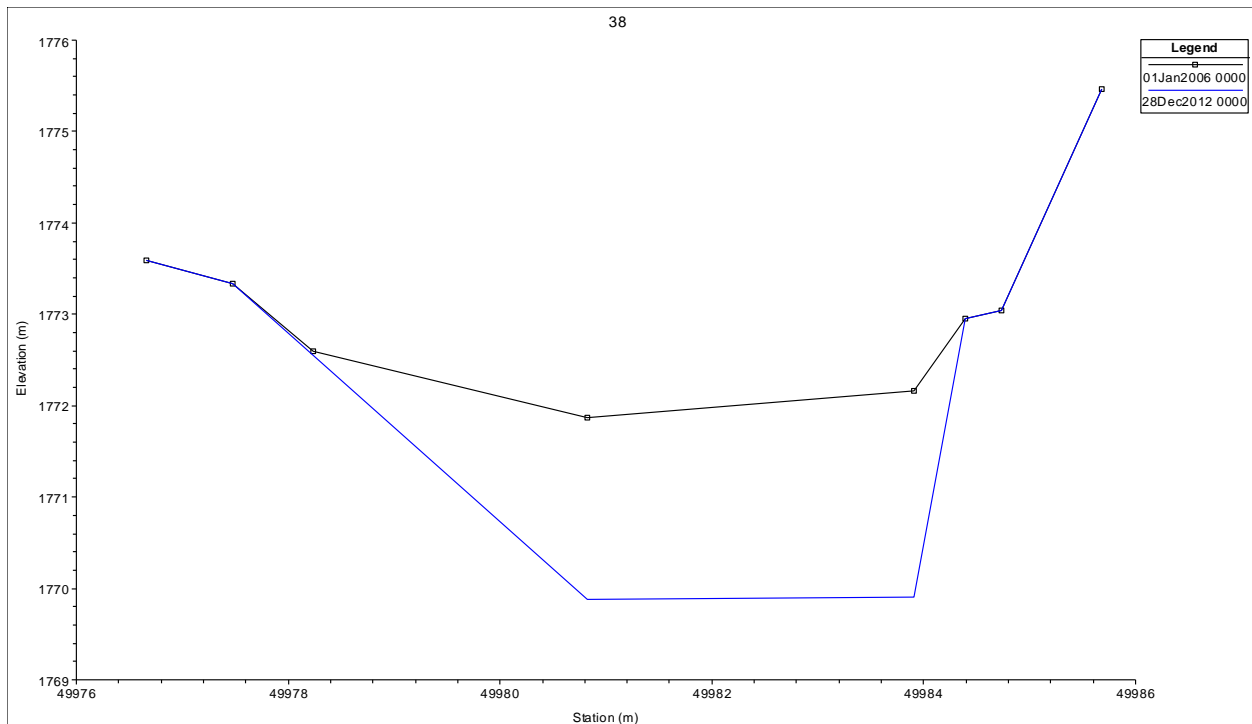


Figure 4-7 Sediment cross section change at station 38

The other result comes as indicated in the figure below neither aggrade nor degrade on both river bank and bed of the channel that shows the channel reach was stable.

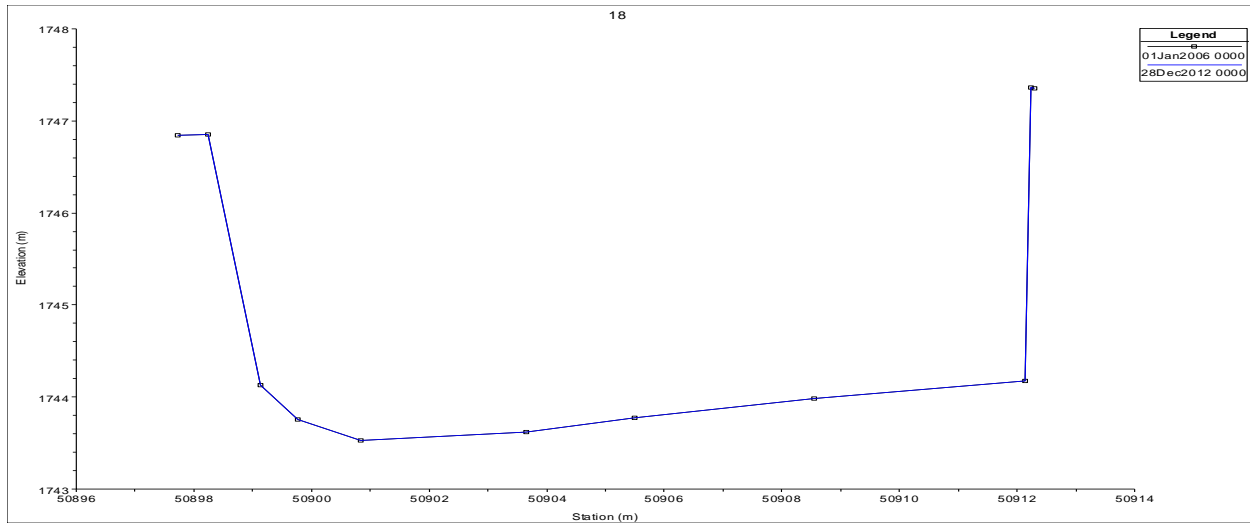


Figure 4-8 Sediment cross section change at station 18

Figure 4-9 and 4-10 below from 2006 to 2012 year the aggradation and degradation pattern how far from year to year, no degradation up to 2010 but later 2011 and 2012 degradation was observed at station 29 whereas at station 30 there were deposition at a year 2006 but in the remaining the degradation were observed.

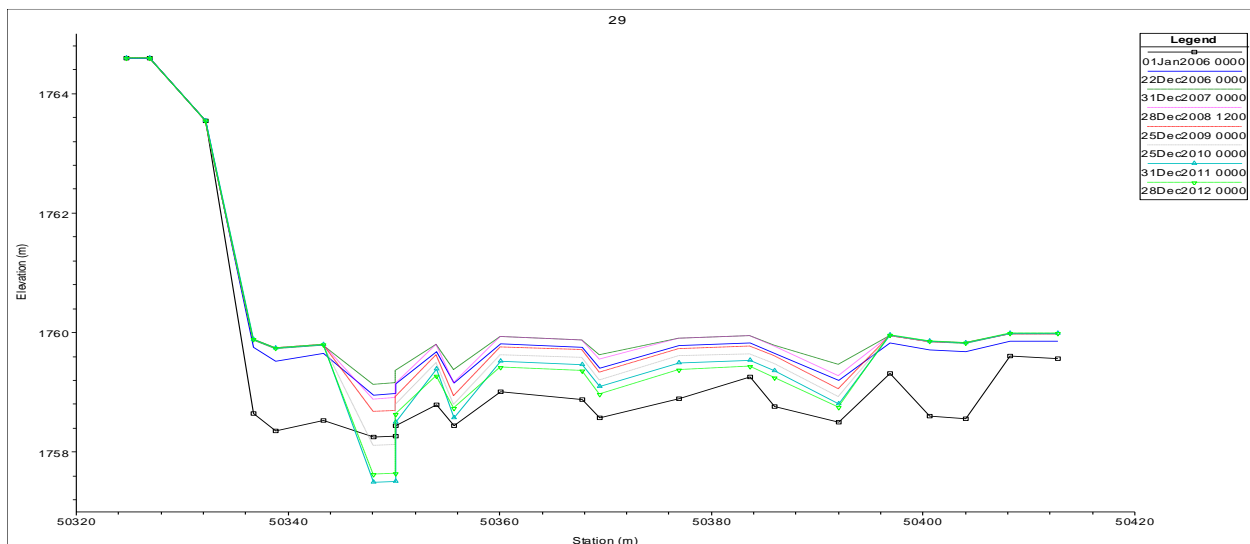


Figure 4-9 Sediment cross section change at station 29

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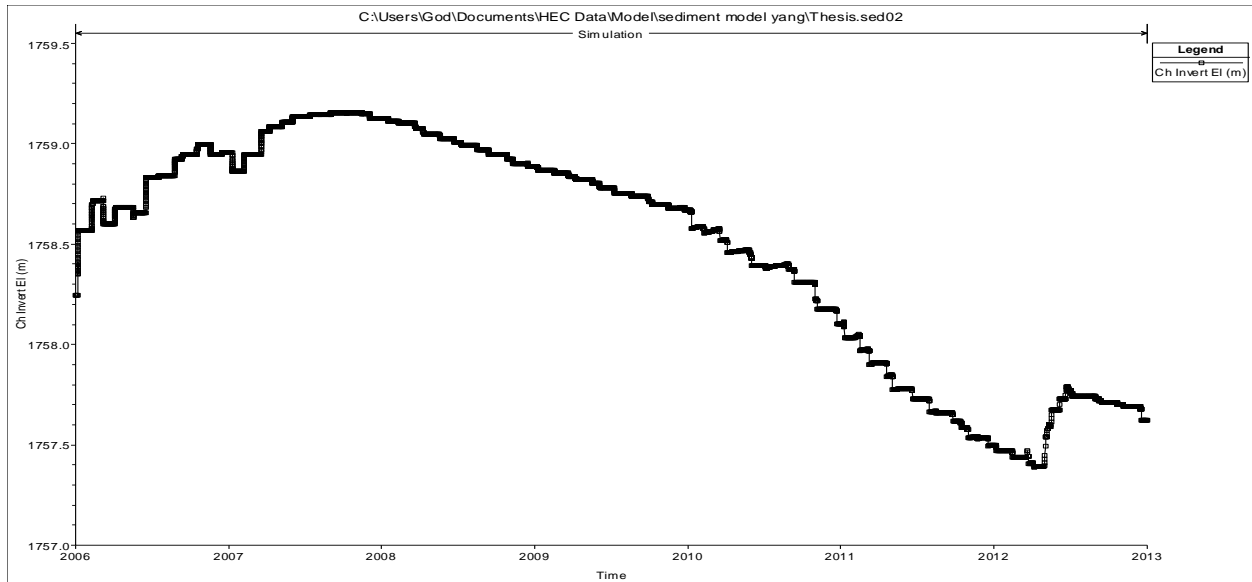


Figure 4-10 Sediment time series at station 29

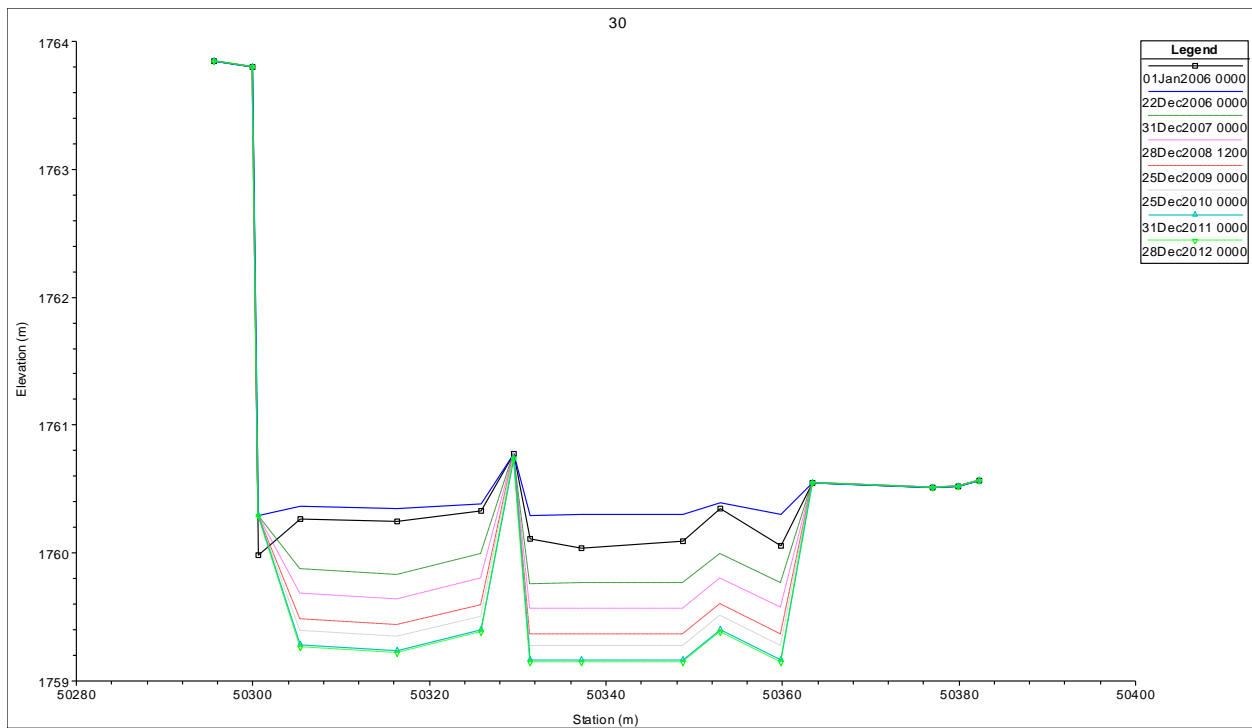


Figure 4-11 Sediment cross section change at station 30

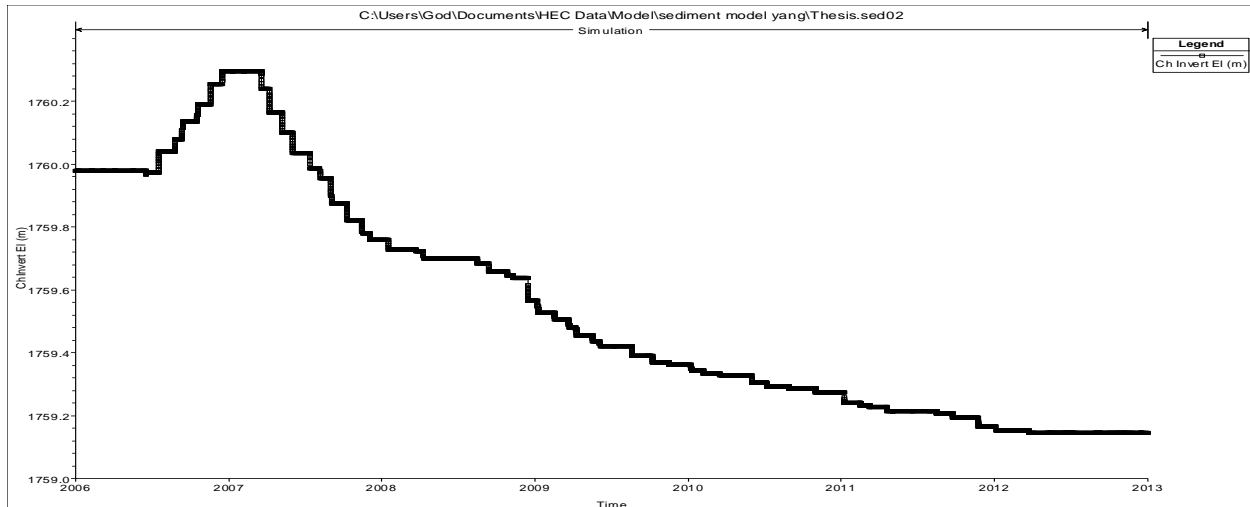


Figure 4-12 Sediment time series at station 30

Another method that was used in this investigation Meyer Peter and Muller which gave an acceptable result in aggradation as compared and contrast to field observation and for the same fashion as Yang sediment transport formula the simulation for 7year daily discharge the study reach was done and deposition or degradation were observed on various reach of Mersa river. Accordingly, Meyer Peter and Muller method the maximum aggradation or deposition 3.33m at station 26 and degradation also 2m observed at station 5,7,11,25,31,36 and 41 as shown in the figure 4-13 and table 4-5 below. Additionally, the average aggradation was 1.12m and degradation also 1.52m thus shows the Mersa reach more disposed to erosion.

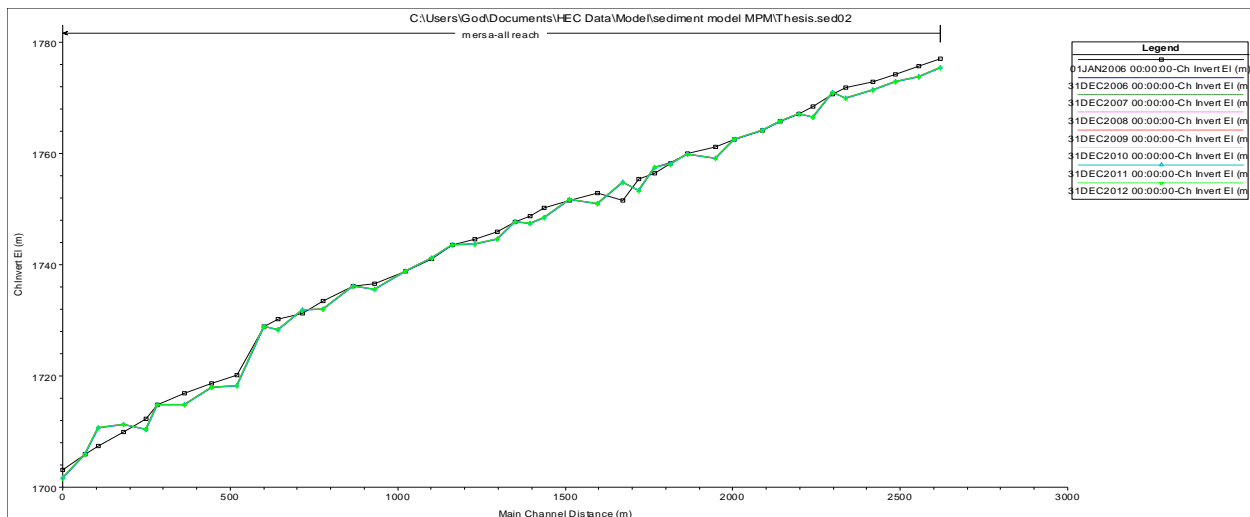


Figure 4-13 Sediment spatial plot MPM

Table 4-5 Channel bed elevation according to MPM

River	Reach	RS	Elevation(m) @Jan, 1, 2006	Elevation(m) @Dec,31,2012	Difference (m)
Mersa	all reach	42	1776.981	1775.391	-1.59
Mersa	all reach	41	1775.755	1773.756	-2.00
Mersa	all reach	40	1774.207	1772.908	-1.30
Mersa	all reach	39	1772.954	1771.409	-1.54
Mersa	all reach	38	1771.871	1769.882	-1.99
Mersa	all reach	37	1770.617	1770.894	0.28
Mersa	all reach	36	1768.513	1766.514	-2.00
Mersa	all reach	35	1767.059	1767.059	0.00
Mersa	all reach	34	1765.785	1765.785	0.00
Mersa	all reach	33	1764.21	1764.21	0.00
Mersa	all reach	32	1762.539	1762.539	0.00
Mersa	all reach	31	1761.182	1759.182	-2.00
Mersa	all reach	30	1759.98	1759.819	-0.16
Mersa	all reach	29	1758.247	1758.062	-0.19
Mersa	all reach	28	1756.402	1757.478	1.08
Mersa	all reach	27	1755.367	1753.367	-2.00
Mersa	all reach	26	1751.532	1754.864	3.33
Mersa	all reach	25	1752.921	1750.922	-2.00
Mersa	all reach	24	1751.589	1751.74	0.15
Mersa	all reach	23	1750.289	1748.462	-1.83
Mersa	all reach	22	1748.751	1747.479	-1.27
Mersa	all reach	21	1747.705	1747.705	0.00
Mersa	all reach	20	1745.997	1744.553	-1.44
Mersa	all reach	19	1744.521	1743.691	-0.83
Mersa	all reach	18	1743.531	1743.531	0.00
Mersa	all reach	17	1741.037	1741.221	0.18
Mersa	all reach	16	1738.831	1738.831	0.00
Mersa	all reach	15	1736.616	1735.5	-1.12
Mersa	all reach	14	1736.084	1736.084	0.00
Mersa	all reach	13	1733.537	1731.953	-1.58
Mersa	all reach	12	1731.328	1731.842	0.51
Mersa	all reach	11	1730.245	1728.246	-2.00
Mersa	all reach	10	1728.954	1728.954	0.00
Mersa	all reach	9	1720.103	1718.157	-1.95
Mersa	all reach	8	1718.622	1717.941	-0.68
Mersa	all reach	7	1716.877	1714.877	-2.00
Mersa	all reach	6	1714.803	1714.83	0.03

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Mersa	all reach	5	1712.324	1710.325	-2.00
Mersa	all reach	4	1709.991	1711.2	1.21
Mersa	all reach	3	1707.437	1710.733	3.30
Mersa	all reach	2	1705.965	1705.965	0.00
Mersa	all reach	1	1703.185	1701.585	-1.60

The figure shows graphical representation of channel bed change daily from 2006 to 2012 along the whole Mersa river reach.

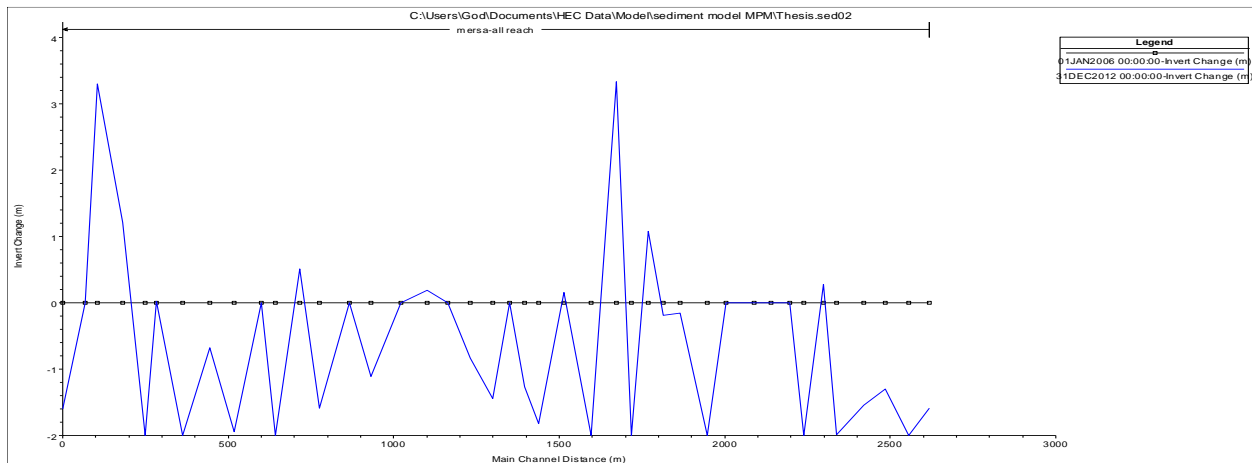


Figure 4-14 Invert change along the Mersa river reach

When we compare the simulation result of both transport function (Yang’s and Meyer Peter Muller’s Method) nearly half of river reach had the similar or same channel bed change especially on channel reach which are neither aggrade nor degrade and some reach had the same degradation.

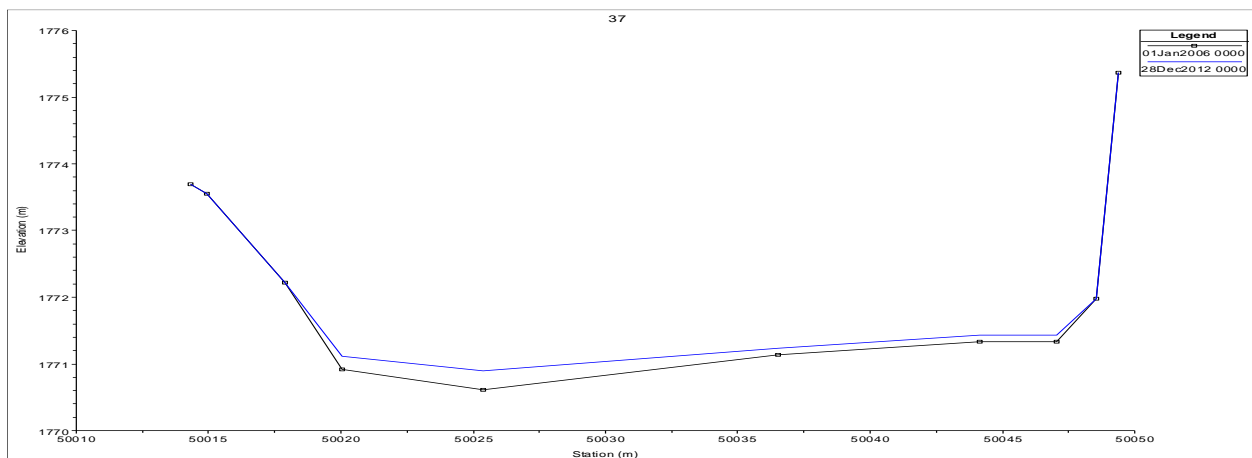


Figure 4-15 Sediment cross section change at station 37

As shown in the figure 4-15 in the station 37 deposition observe over entire channel bed excluding both river bank.

As we can see in the figure below 4-16 for station 30 deposition observed near to left river bank, at channel degradation and on right river bank aggradation was observed. Additionally, trend of aggradation and degradation for the complete 7year daily discharge simulation as shown in the figure 4-17 below the result shows that only for the first year to half of a year the trend was not uniform after half of 2006 to the end 2012 the trends were uniform.

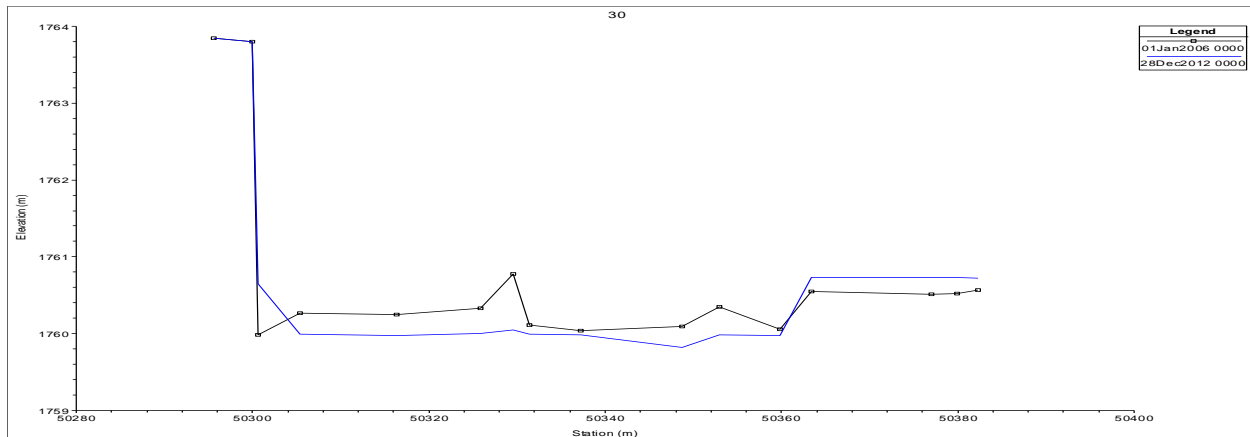


Figure 4-16 Sediment cross section change at station 30

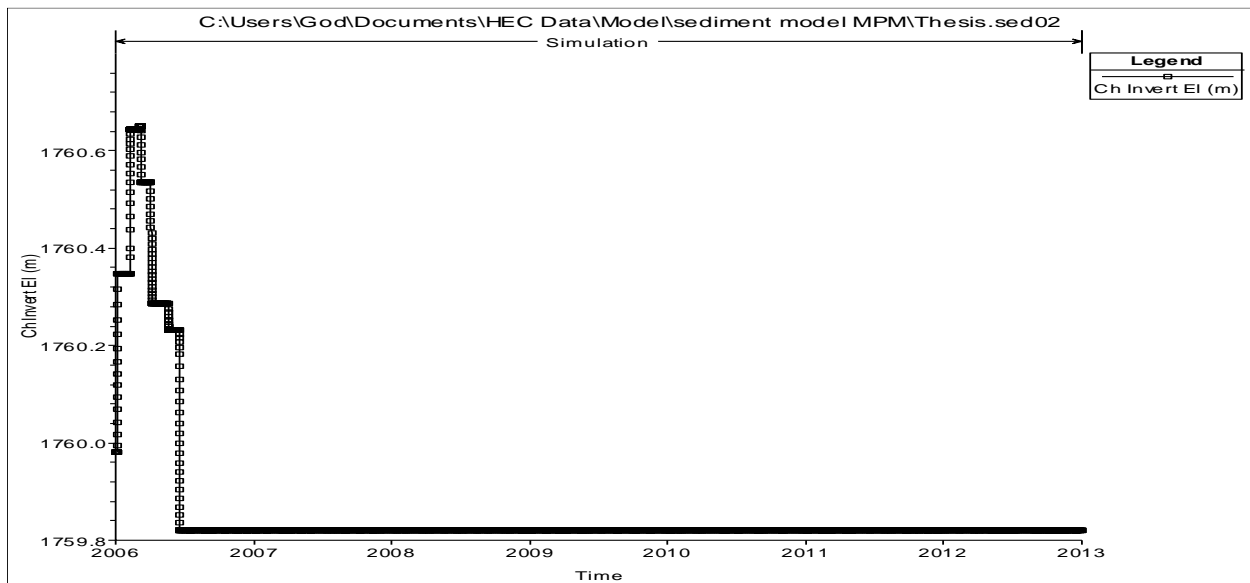


Figure 4-17 Sediment time series station 30

Whereas in figure 4-18 at station 29 on near to both bank the large aggradation was observed while at middle of reach small both aggradation and degradation was observed.

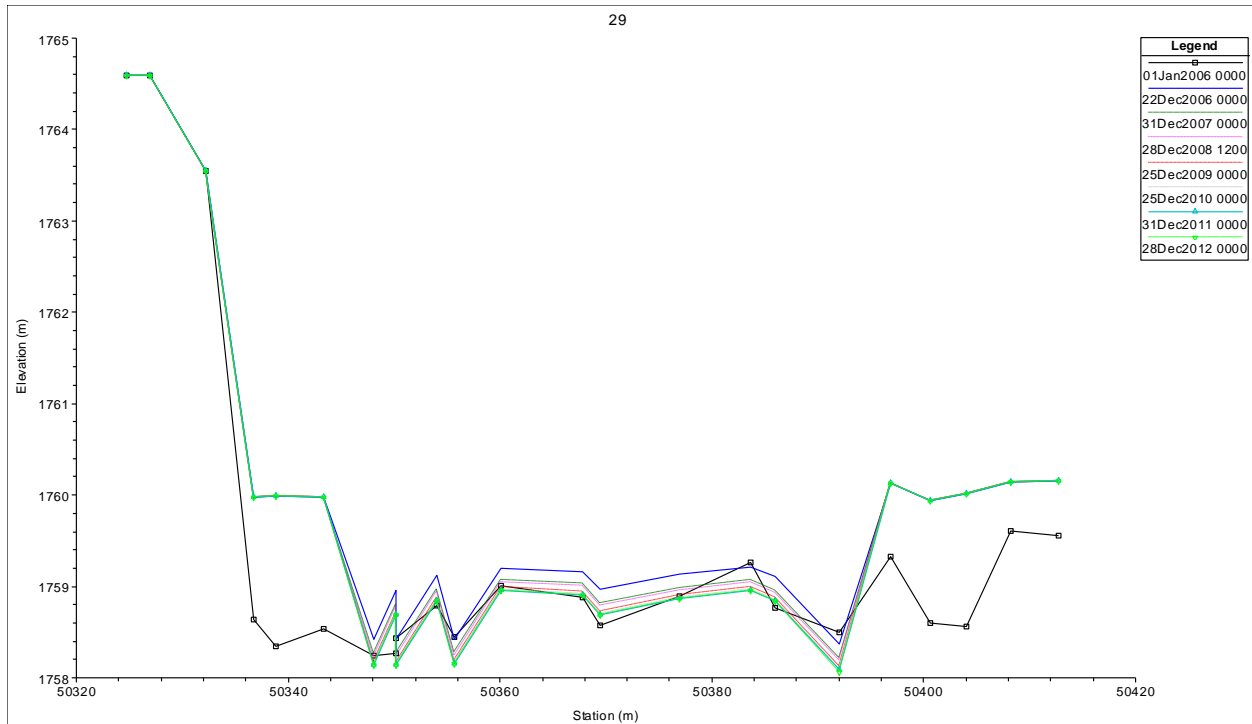


Figure 4-18 Sediment cross section change 7year simulation at station 29

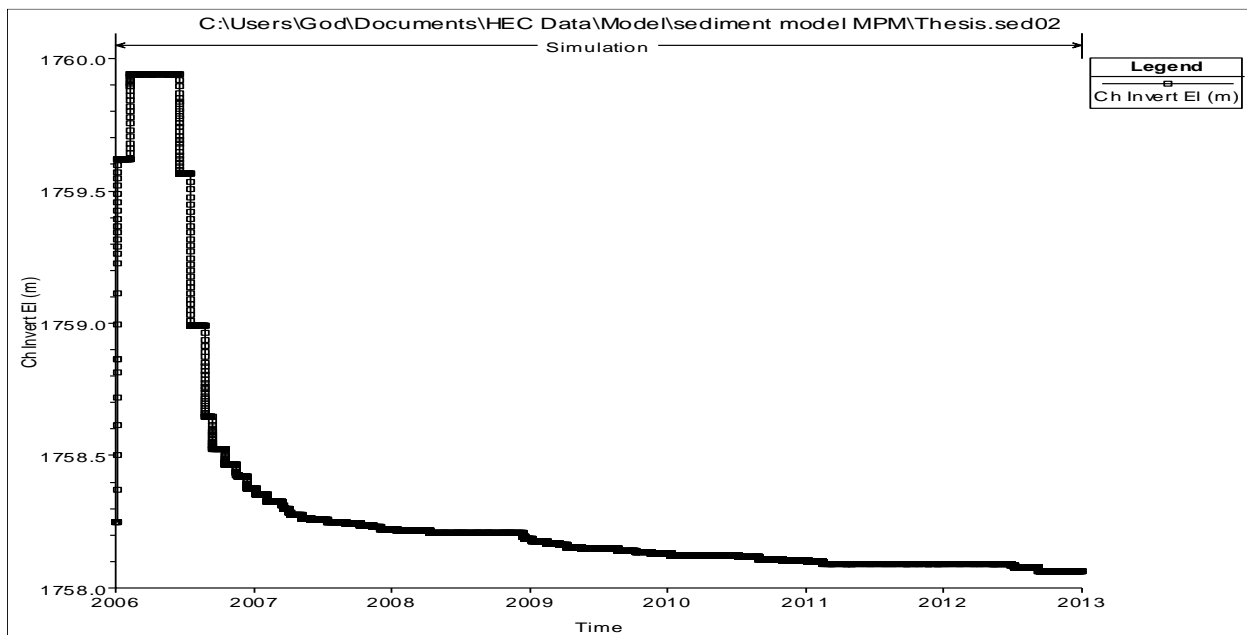


Figure 4-19 Sediment time series station 29

As shown in above figure at station 30 the aggrade or degrade pattern for the first 2year are quick while to change pattern not be exactly uniform but gradually varied from year to year.

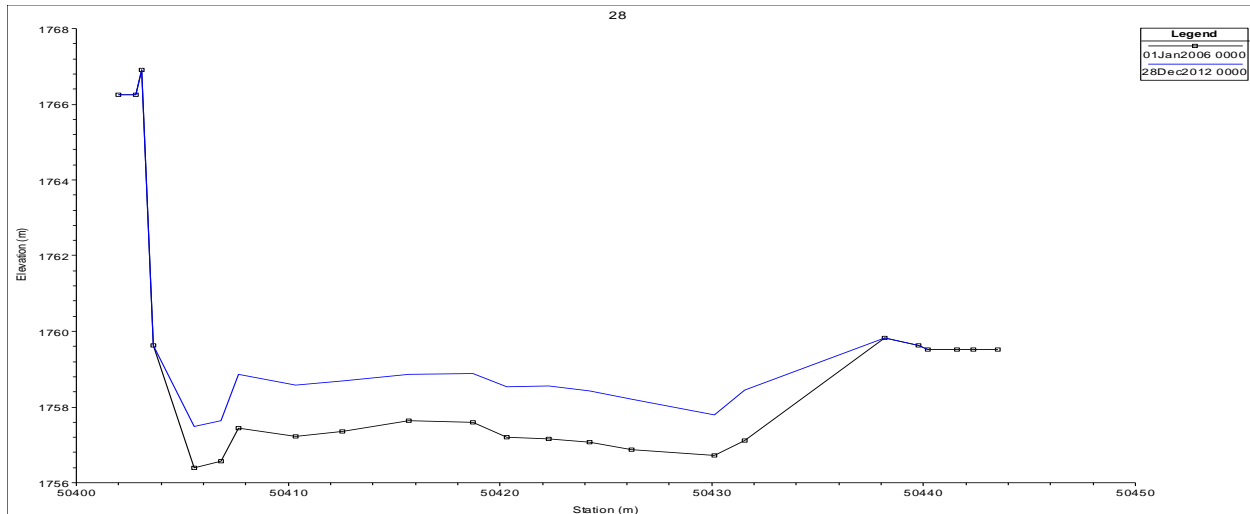


Figure 4-20 Sediment cross section change at station 28

As shown in the above figure at station 28 aggradation were observed across channel except both right and left channel bank and the trends for simulated year similarly shown in the figure below again here for the 2006 year up to June the trend was varies daily but later to 2012 the trend become uniform.

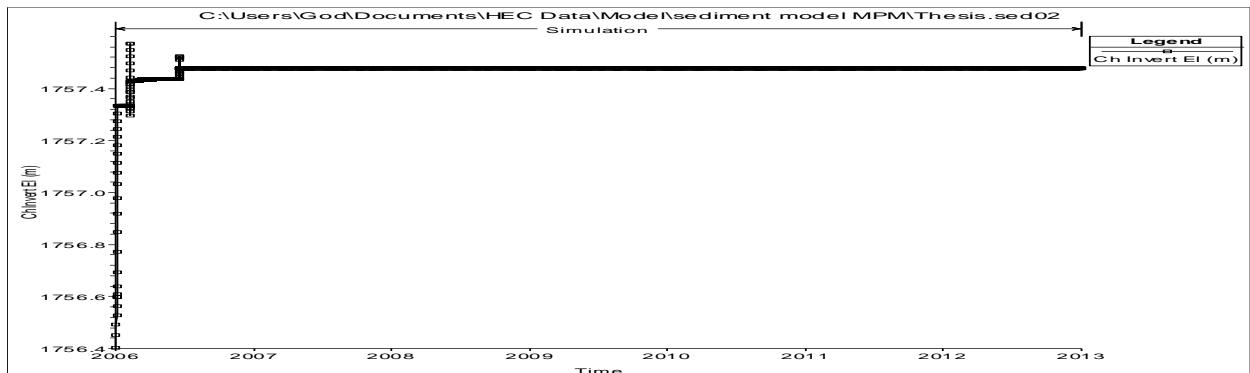


Figure 4-21 Sediment time series station 28

According to above two scenarios (Yang transport method and Meyer Peter and Muller transport method) the result could be grouped in three condition as follows. The initial condition near to 49% of Mersa river reach had equivalent result on both transport method, the second condition near to 46% of Mersa river reach had also resemblance result and the remaining 5% of Mersa river reach had opposite mean on one method deposition on the other degradation. Finally, from thus which works better or acceptable for the reach of channel must be decided that helps to recommend appropriate mitigation measure to change of channel bed. To differentiate the appropriate one for

study river reach field observation and sample cross section surveyed after one-year later on January 2020 (the same bench mark as before) was taken compared it with one-year model result from both methods. The aggradation or degradation data were surveyed at 2019 and the later 2020 showed on the table below for selected river reach at upstream and downstream reach.

Table 4-6 One-year simulation result and field surveyed collected data comparison

Channel bed change	River reach	Sediment transport formula		Field surveyed cross section
		1year simulation result (m/year)		1year later collected (m/year)
		Yang	Meyer Peter and muller	
Aggradation	Upstream reach	1.12	1.08	1.07
	Downstream reach	0.22	1.21	0.21
Degradation (negative)	Upstream reach	1.18	2	1.16
	Downstream reach	2	1.83	1.94

Comparison between the simulation result and the reality on field was as shown above in the table. The result of upstream reach aggradation or deposition according to Meyer Peter and Muller (MPM) and Yang as compare and contrast to the field observation Yang over estimate but MPM best fit for aggradation of upstream river reach. Downstream reach aggradation compared to site was fitted to Yang rather than MPM because it over estimates the deposition. Degradation in both upstream and downstream reach were fitted with Yang sediment transport formula than MPM transport function. According to MPM result degradation at upstream over estimates than the realistic situation while at downstream reach it under estimate than the field observation. In conclusion Yang gives more realistic vertical change which compared with MPM therefore Yang sediment formula was the best representative transport function for our Mersa river reach.

4.4.1.2 Sediment Quantity Change

As discussed above it shows that there was vertical change or obviously the channel was not stable in addition to these vertical changes the quantity of sediment entry (mass entry) and sediment leave (mass leave) in the channel must be explained. So, the mass entry to Mersa river and mass leave in each year from Mersa river is presented in the following table and figures.

Table 4-7 Sediment mass in and out difference (tones)

RS	station (m)	year						
		2006	2007	2008	2009	2010	2011	2012
42	0	-164.97	14.903	149.523	181.474	181.473	183.196	184.574
41	67.31	-110.34	66.724	239.977	285.317	289.504	292.634	305.75
40	106.02	684.924	1018.01	1202.82	1355.2	1369.11	1428.37	1457.69
39	181.99	1104.62	1374.98	1658.88	1683.36	1686.66	1732.9	1756.24
38	249.08	1434.49	2029.85	2332.07	2469.15	2486.37	2501.36	2539.13
37	282.7	1884.76	2231.31	2571	2608.48	2609.69	2610.4	2625.43
36	363	214.812	15.924	122.949	-36.898	-36.899	-36.903	-27.872
35	444.68	1158.14	1702.16	2159.63	2210.98	2211.74	2211.95	2233.17
34	518.74	4321.33	4096.46	1956.09	1800.21	1805.94	1808.49	1858.83
33	600.94	-367.56	62.109	66.93	66.934	66.93	66.937	80.629
32	641.68	677.385	654.332	654.426	654.426	654.437	654.438	528.101
31	714.72	2580.64	3085.7	3091.33	3091.33	3091.34	3091.36	3114.65
30	776.64	1728.14	706.184	-508.85	-988.57	-1183.2	-1362.8	-647.78
29	866.84	-4733.3	-4451.3	-4451.3	-4451.3	-4451.3	-4451.3	-4451.3
28	932.18	-4676.8	-4772.8	-4765.1	-4746.6	-4734.1	-4717.5	-4707.5
27	1022.57	-1531.3	-1357.7	-1357.7	-1357.1	-1357.1	-1357.1	-1355.6
26	1100.25	2177.04	-1494.2	-1494.2	-1465.7	-1459.7	-1459.6	-1387.4
25	1163.95	-713.56	-711.48	-711.48	-711.35	-711.35	-711.35	-711.32
24	1230.75	-2012.1	-1966.9	-1858	-1826.5	-1764.2	-1709.9	-1651.7
23	1298.41	-2330.2	-2330.2	-2330.2	-2330.2	-2330.2	-2330.2	-2335.4
22	1351.16	281.008	282.024	282.023	282.114	282.164	282.211	286.912
21	1394.18	-672.26	-631.36	-620.41	-604.97	-598.72	-598.32	-589.63
20	1437.9	-463.48	-463.49	-463.49	-463.48	-463.48	-463.48	-463.48
19	1513.54	-493.39	-163.75	56.002	276.053	374.457	446.016	812.447
18	1595.55	-1477.7	-1480	-1407.3	-1480.9	-1458	-1439.8	-1573.7
17	1673.33	2726.1	2758.29	2637.66	2841.86	2851.89	2987.15	1372
16	1718.33	2422.78	4368.54	8311.48	9405.92	9567.43	9442.28	9376.98
15	1767.71	8494.48	10442.2	7791.33	7373.74	7335.98	7375.91	7381.54
14	1814.17	4675.69	5525.36	4422.77	3489.8	2881.41	2352.34	2350.84
13	1865.5	90.953	-3272.1	-4531.5	-5957	-6674.4	-7682.1	-8623.3
12	1948.03	-5018.1	-7389.9	-7389.9	-7389.9	-7389.9	-7389.9	-7389.9
11	2004.75	-6025	-6025	-6025	-6025	-6025	-6025	-6025
10	2088.16	-9560.6	-9560.6	-9560.6	-9560.6	-9560.6	-9560.6	-9560.6
9	2140.46	-4652.4	-4652.4	-4652.4	-4652.4	-4652.4	-4652.4	-4652.4
8	2197.35	-939.65	-938.46	-936.99	-936.99	-936.99	-936.99	-936.99

7	2240	-760.38	-756.98	-756.98	-756.98	-756.98	-756.98	-756.98
6	2297.64	-761.97	-757.39	-757.24	-757.24	-757.24	-757.24	-757.24
5	2338.25	-830.81	-864.41	-864.41	-864.41	-864.41	-864.41	-864.41
4	2419.54	-317.75	-272.73	-260.61	-260.61	-260.61	-260.61	-260.61
3	2485.51	-1467.3	-2453.4	-2768.6	-2768.6	-2768.6	-2768.6	-2768.6
2	2555.89	-1875.7	-1875.7	-1875.7	-1875.7	-1875.7	-1875.7	-1875.7
1	2618.36	-973.66	-973.66	-973.66	-973.66	-973.66	-973.66	-973.66

Table 4-7 shows the amount of sediment mass change in sediment at the channel, the negative sign and positive sign indicates erosion and deposition respectively the cumulative mass in and out from the channel see appendix D. Finally, Mersa river affected by erosion than deposition in average cumulative 22,470 tons per year sediment eroded from the channel. The delineated Mersa catchment was under sub-basin Awash Terminal and According to [39] report the total erosion generated from this sub-basin or Awash Terminal was 38.2 Mt/yr. the result obtained from the Mersa river 22.47Kt/yr. is acceptable. For illustration the profile plot of cumulative mass in or out at and each soil material quantity at 2006 shown at figures below.

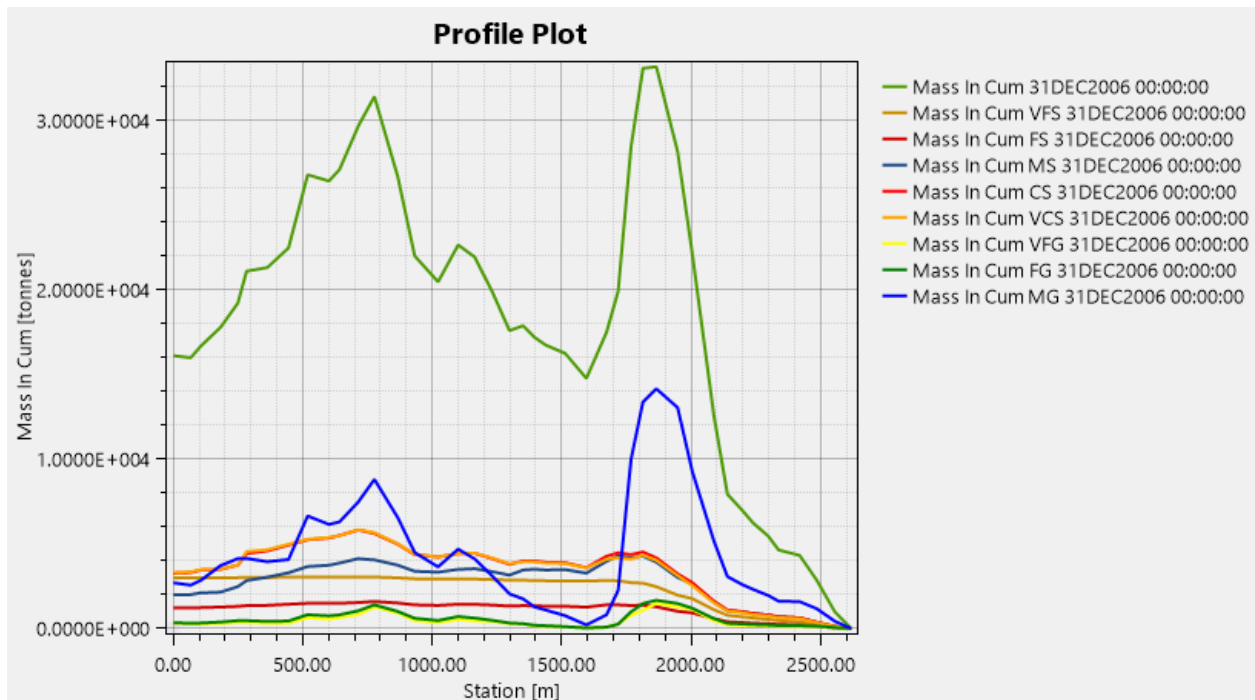


Figure 4-22 Sediment in to study channel 2006

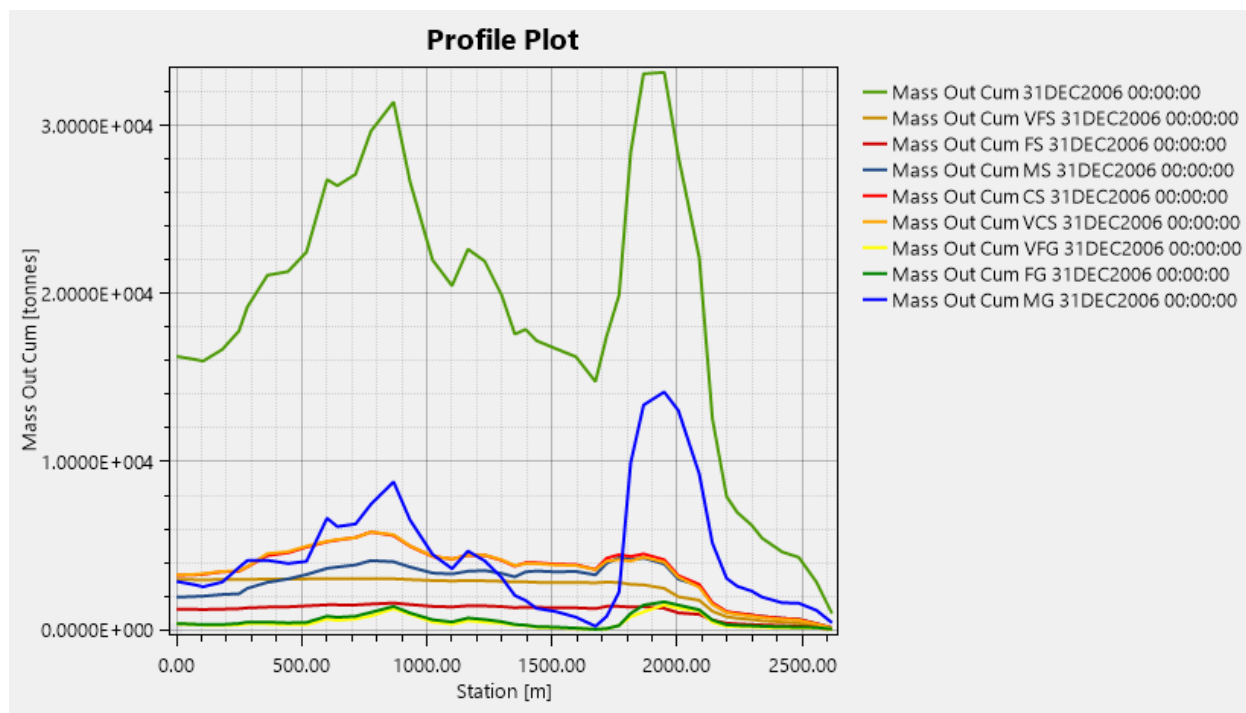


Figure 4-23 Sediment out from study channel at 2006

4.4.2 Channel Bank Stability Analysis

As mentioned in the previous chapter Bank Stability and Toe Erosion model simulation was done static ground water table for ground water method and bank failure method done with method of slice. BSTEM analysis result shows that Mersa rive all reach factor of safety were greater than unity except at reach 33 and 26 safety factor was 0 for right bank and left bank respectively. Both right and left bank were stable (no bank failure) and there was also no toe erosion. The stability condition both bank and toe station were stable against severe erosion. The table and figure below show that shear stress produced by flow for entire simulation period (start from 2006 to 2012) the maximum or extreme shear stress was 152Pa at river reach 23 in the year 2008 and average shear stress 10.6Pa.

Table 4-8 Mersa river reach shear stress

River	RS	Shear Stress (pa)						
		2006	2007	2008	2009	2010	2011	2012
Mersa	42	6.00	0.80	5.13	0.48	0.48	0.09	0.43
Mersa	41	0.95	6.31	18.07	3.39	3.39	0.80	3.76

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Mersa	40	0.84	0.26	1.09	0.14	0.14	0.03	0.13
Mersa	39	8.81	5.48	12.99	4.40	4.40	4.70	4.34
Mersa	38	0.06	0.01	0.80	0.00	0.00	0.00	0.00
Mersa	37	1.43	0.70	4.15	0.45	0.45	0.08	0.41
Mersa	36	0.06	0.01	0.64	0.00	0.00	0.00	0.00
Mersa	35	2.57	0.99	14.14	0.65	0.65	0.33	0.63
Mersa	34	1.77	1.04	2.61	0.52	0.52	0.07	0.47
Mersa	33	1.09	0.63	4.60	0.34	0.34	0.13	0.34
Mersa	32	1.15	0.54	1.02	0.37	0.37	0.03	0.31
Mersa	31	0.37	0.30	4.28	0.16	0.17	0.08	0.17
Mersa	30	2.30	1.04	0.86	1.59	1.59	0.11	1.56
Mersa	29	2.16	0.56	1.86	0.14	0.01	0.00	0.00
Mersa	28	30.69	16.66	45.06	12.59	12.61	10.25	11.97
Mersa	27	2.03	0.43	2.87	0.15	0.15	0.10	0.15
Mersa	26	8.00	4.48	16.66	2.76	2.69	0.64	2.22
Mersa	25	1.31	0.33	1.96	0.06	0.04	0.01	0.01
Mersa	24	1.55	0.94	3.46	0.67	0.68	0.18	0.69
Mersa	23	87.37	49.74	152.27	31.34	31.34	5.99	29.94
Mersa	22	0.24	0.12	1.14	0.09	0.10	0.05	0.12
Mersa	21	4.05	1.72	9.37	0.94	0.94	0.17	0.89
Mersa	20	2.62	1.25	2.39	0.77	0.77	0.19	0.74
Mersa	19	0.11	0.04	0.64	0.02	0.02	0.00	0.03
Mersa	18	5.37	3.23	9.65	2.00	2.00	0.53	1.92
Mersa	17	1.95	0.98	5.24	0.61	0.61	0.12	0.59
Mersa	16	4.55	2.19	7.72	1.37	1.37	0.42	1.30
Mersa	15	0.07	0.03	1.15	0.01	0.01	0.00	0.01
Mersa	14	3.50	3.09	5.20	2.26	2.26	0.81	2.59
Mersa	13	0.53	0.13	0.23	0.00	0.00	0.00	0.00
Mersa	12	3.25	3.11	5.99	2.26	2.26	0.41	2.58
Mersa	11	0.32	0.05	2.87	0.01	0.01	0.00	0.01
Mersa	10	4.07	2.50	8.72	1.60	1.60	0.54	1.33

Mersa	9	1.46	0.74	4.16	0.49	0.49	0.11	0.44
Mersa	8	8.58	4.71	11.92	2.79	2.79	1.31	3.10
Mersa	7	2.90	0.87	4.53	0.36	0.40	0.03	0.34
Mersa	6	3.81	2.03	13.27	3.66	1.32	0.40	3.97
Mersa	5	7.79	3.80	11.77	0.90	2.35	0.47	0.84
Mersa	4	0.66	0.25	1.83	0.64	0.13	0.03	0.61
Mersa	3	5.88	2.99	14.72	2.03	2.04	0.81	1.99
Mersa	2	8.45	4.76	16.33	3.46	3.46	2.16	3.41
Mersa	1	4.45	3.06	7.95	1.86	1.86	0.48	1.80

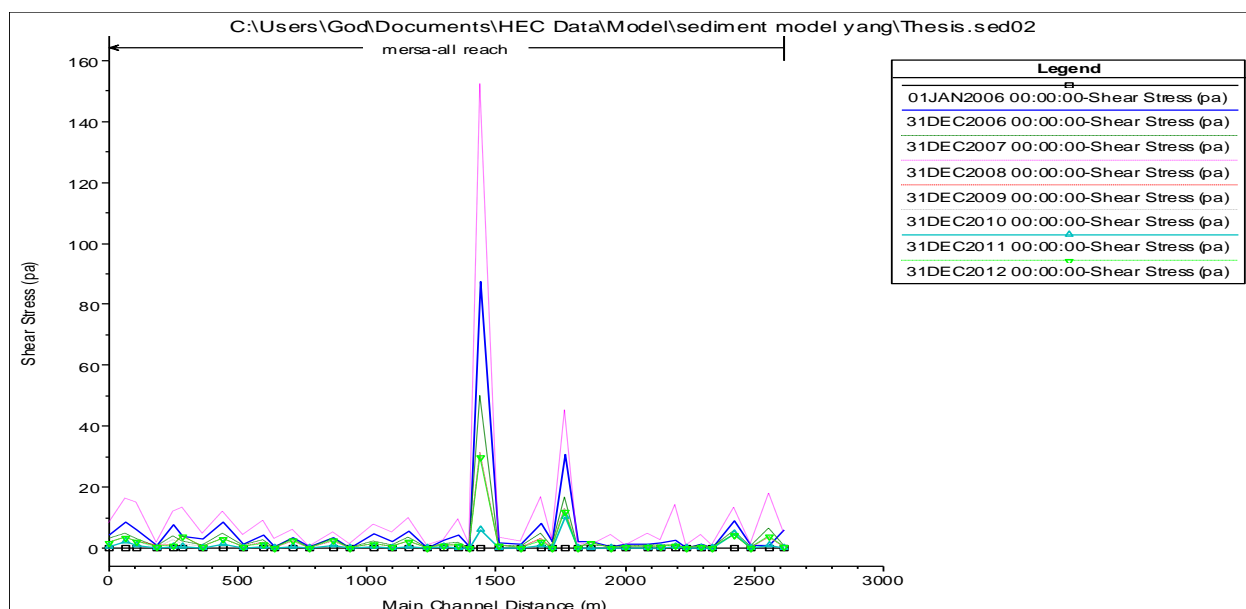


Figure 4-24 Mersa river Shear stress for simulation period 2006 to 2012

4.4.3 Water Surface Profile Computation and Flood Inundated map

4.4.3.1 Water surface profile at different discharge

The water surface profile for 2, 10, 50 and 100-year return period of peak discharge was computed in the model using Manning's formula by considering gradual varied flow (direct step iteration method). The scenario for maximum discharge of 2-year, 10-year, 50-year and 100-year return period were discussed below.

A. 2 year and 10-year return period design discharge scenario

From the result shown in the model 2year and 10year design discharge nearly accommodated with in a floodplain limit in all reach of Mersa station except on some reach which had the small height river bank under one or both banks.

For illustration, in the figure below in the left side river bank height was large while the right bank height small even if the 2year design discharge was accommodated but for 10year return period peak flood discharge the catchment would be flooded since there were 0.35m excess flood flow on that side.

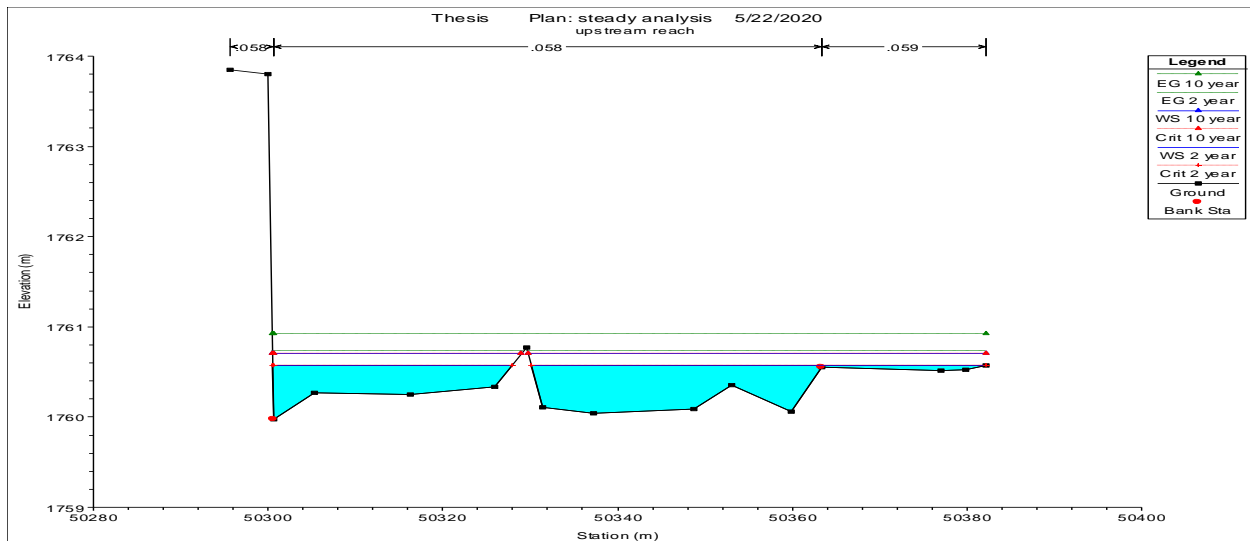


Figure 4-25 Cross section plot river station 30

In the same fashion at station 21 at shown below on the left side again because the height of the bank was small there were excess flood.

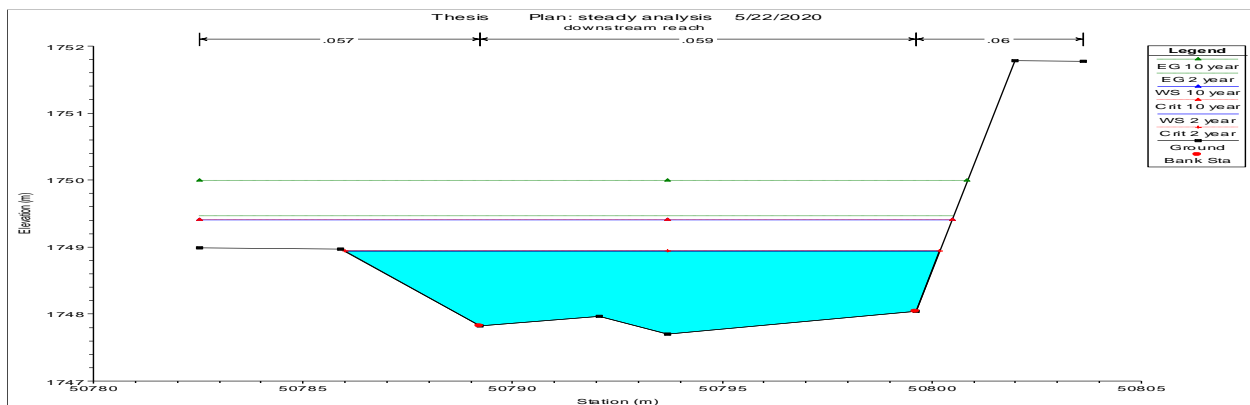


Figure 4-26 Cross section plot river station 21

As shown in the situation which happen bank height difference for thus 10year return period design discharge there would be possibility an area severe by flood thus cause to loss agricultural or irrigation land and other community's property while the bank full discharge housed on limits. Generally, peak discharge of 2year and 10year recurrence interval were accommodated through in flood plain limit.

B. 50 year and 100-year recurrence interval scenario

As shown the model result in the design discharge of 50 and 100year return period there could be an area flooded the reality also approve the model result especially from station 27 up to 34 the significance area had been flooded due to this the people around that losses their agricultural land and till the their home also in danger during my field time I have made interview the person who live on that area and told me due to damage of their production land they have feed themselves by extract sand from the channel during dry season and sold to for who needs construction material.

Totally the core problem was the variation of bank height means the bank height is vary due to natural terrain and artificial man made retaining wall on one side only thus is usual situation which lead to flooded on the side which had small bank height small on the contrary significance area would be flooded on both right and left side which had small height from the preceding station. River reach started from 5 to 9 there would be an area flooded both in the left and right bank.

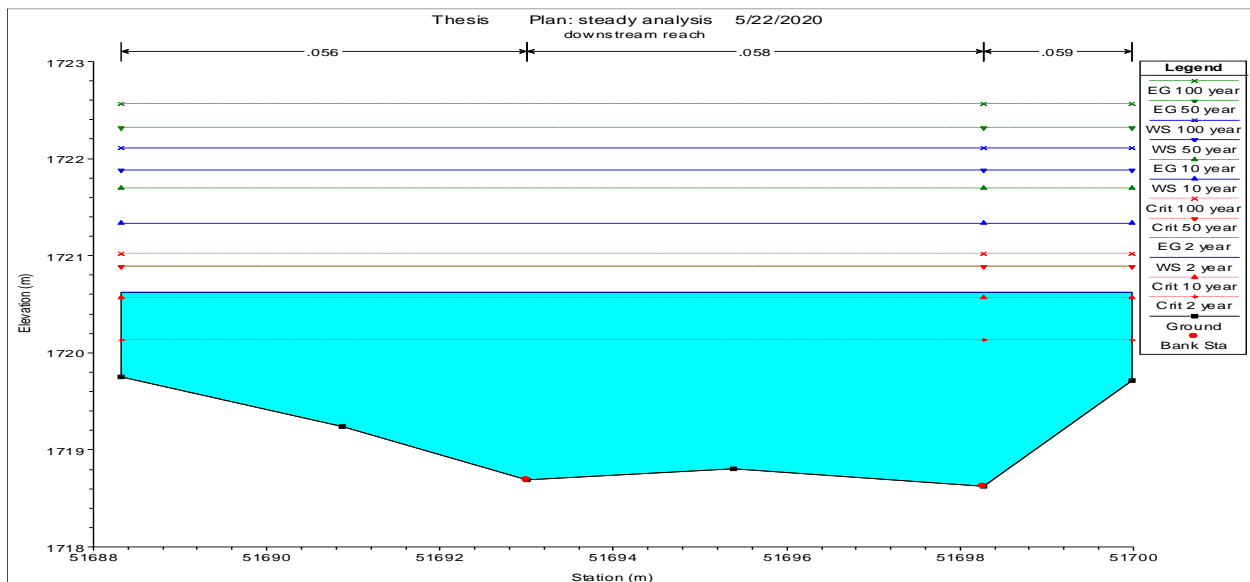


Figure 4-27 Cross section plot river station 8

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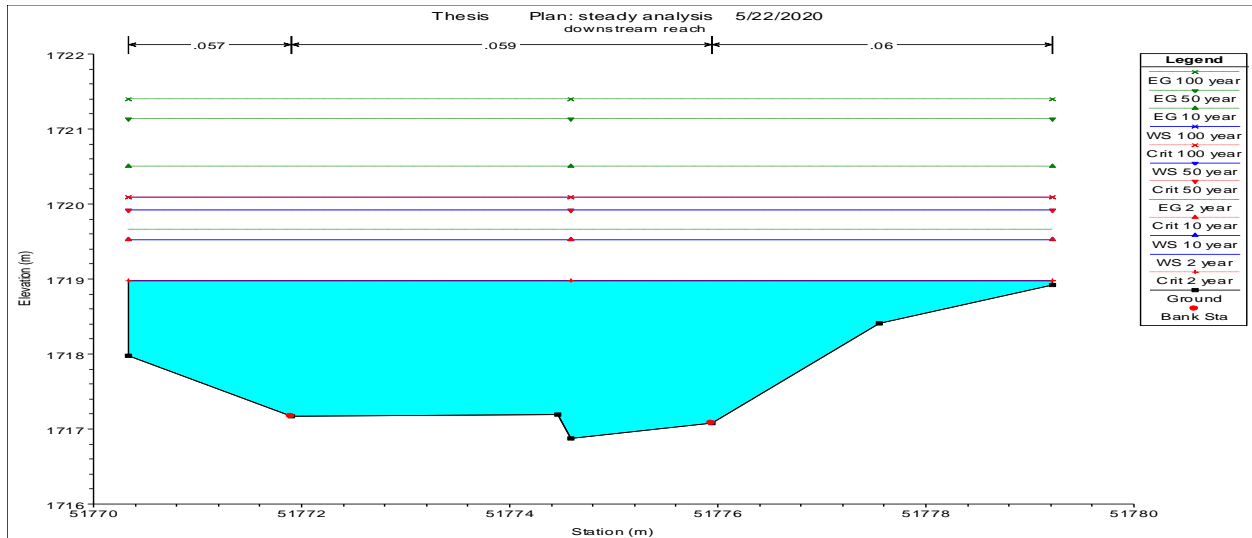


Figure 4-28 Cross section plot river station 7

As shown above at station 7 and 8 there 2m and 1.95m excess flood on both left and right side respectively so the area and other property would be loosed.

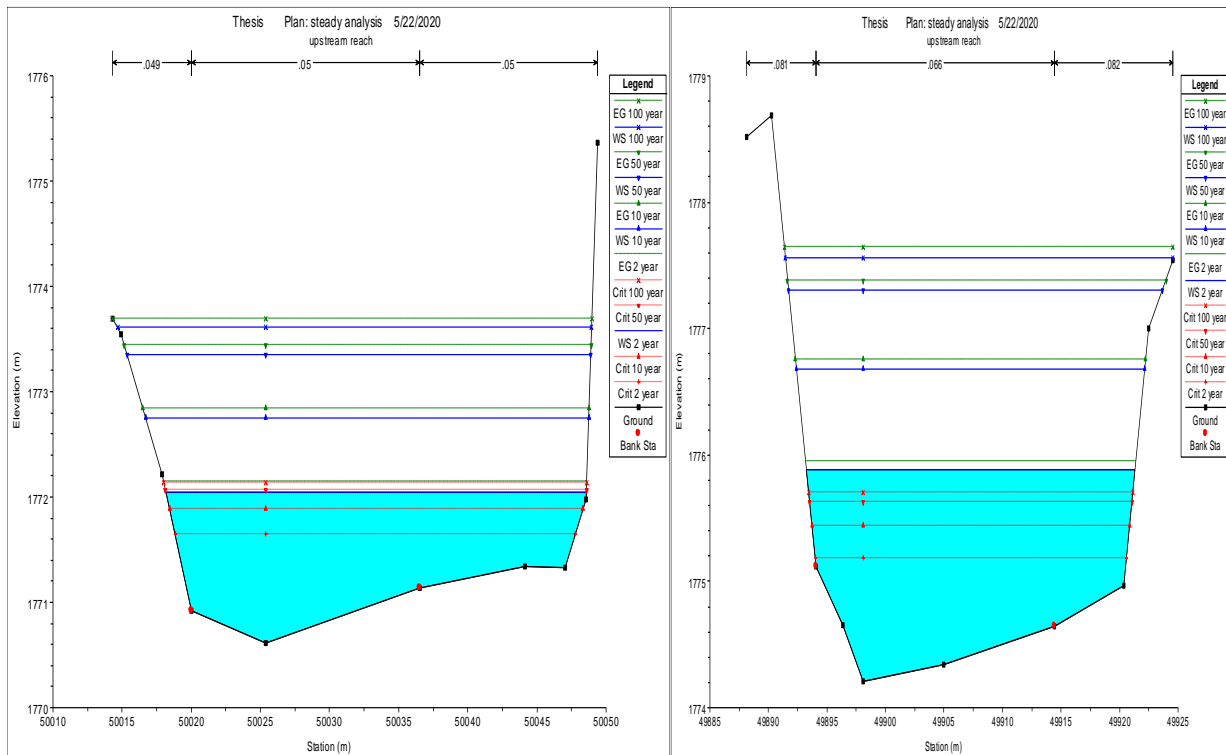


Figure 4-29 Cross section plot river station 37 and 40

As shown above in the river station 37 and 40 the area would be flooded on left side at river station and right side respectively. Generally, the problem more observed that in the upper reach because of bank height difference and in the downstream reach both small bank height on both sides as compare to the preceding river reach in addition to the bank height difference to each other. Even though there are reach which would accommodate design discharge of all recurrence interval with in the floodplain limit.

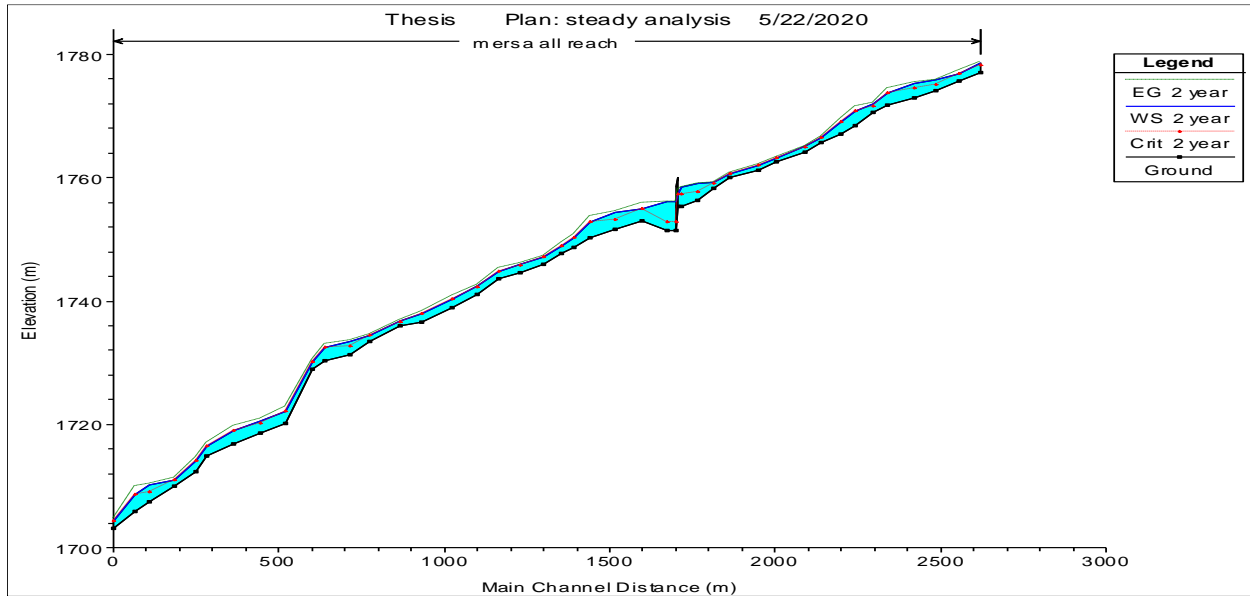


Figure 4-30 Bank full discharge profile plot

As shown in the figure 4-28 for bank full discharge above no over topping to the river edge. It is clear that water surface profile increase as recurrence interval increase so, for the all 10year, 50year and 100year return period the design discharge not accommodated as shown in the figure above overtopping on either one or both bank and back water effect from bridge specially for upper reach.

4.4.3.2 Flood inundated map

Flood inundated map was generated after post process in HEC-GeoRAS having input water surface elevations TIN and cross section (XS) cut lines, within the limits of the bounding polygon. Floodplain mapping was completed after water surface generation and flood plain delineation using raster finally the flood plain delineated, velocity mapping and shear stress mapping produced for corresponding profile. The flood inundated, velocity map and shear stress map of the area is shown in the following figures.

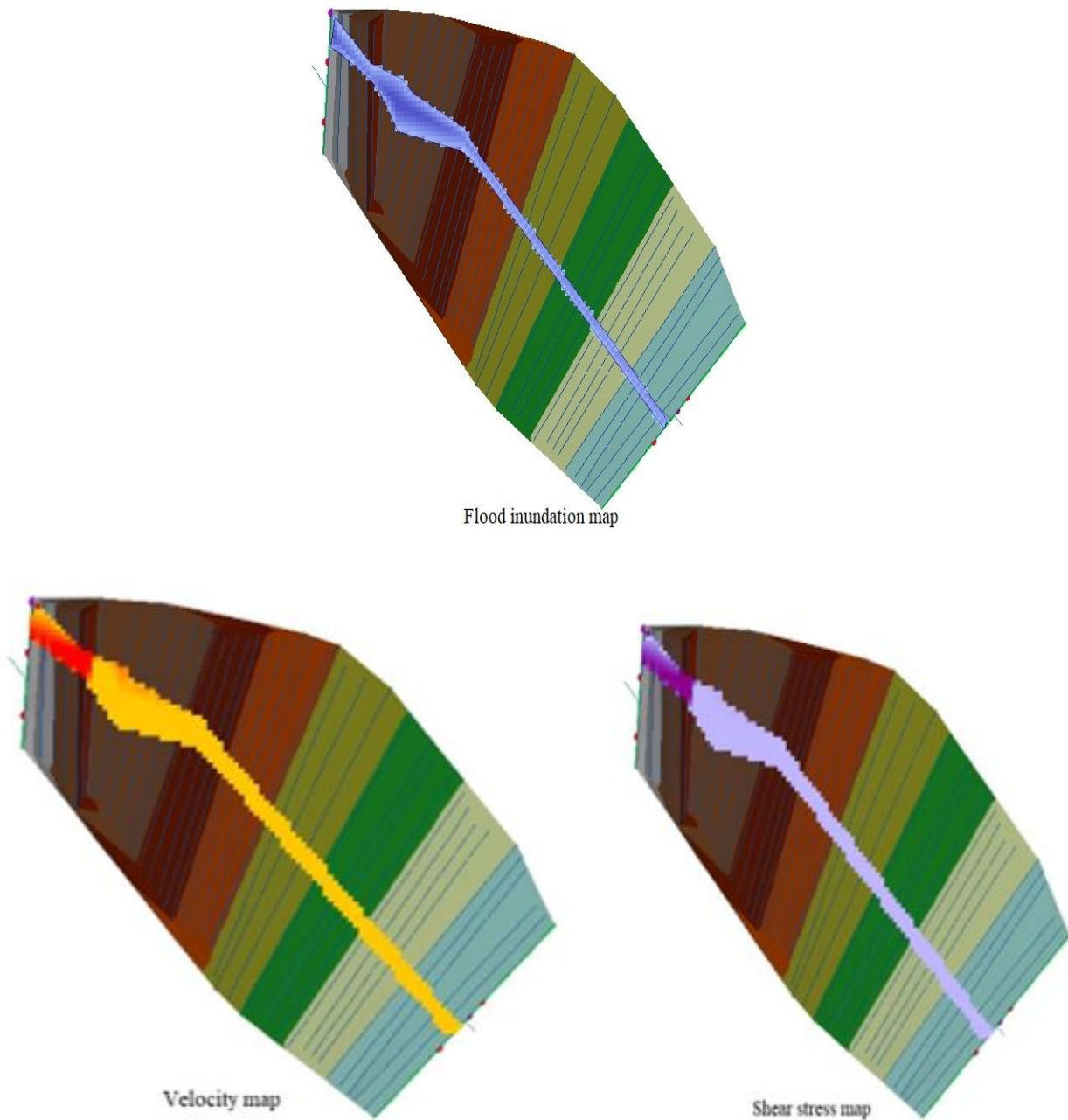


Figure 4-31 Flood inundation map velocity map and shear stress map

As we see in figure 4-29 the flood highly affected adjacent area of study reaches at upstream part as compare to the whole Mersa river and the velocity with shear stress produced by the peak flood in the same fashion maximum in the upstream.

4.5 Discussion on Results

4.5.1 Aggradation and Degradation

Channel bed instability occur when a visible vertical change is observed over a fixed period of time. This vertical change can be roughly categorized in to two classes either which are aggradation or degradation. Degradation would happen water shear force higher than the force of soil particle then the particle starts to transported in this case discharge flow erodes the channel bed while when river bring high sediment beyond its limit mean the shear of the fluid not capable to carry sediment they are deposited on channel bed we call it aggradation.

As compare to the reality at field upper reach were estimated by MPM transport method from thus on reach 37 and 38 were observed and lower reach estimated by Yang method on reach 26,12,9,8,6,5,4,3 also deposition observed while on reach 38-42, 22,25,19-20,15,13,11,7 and 1 were channel bed erosion detected lastly the remaining shows neither aggrade nor degrade. Mersa river reach exhibits both aggradation and degradation on a reach high sediment comes from upper reach when becomes beyond its capacity the sediment deposited on one side the flow will continue other side by changing its course and eroding low sediment. The other condition the river reach continuously aggrade or degrade for entire period with different depth of change. Even if aggradation observed in Mersa river reach as compare to degradation the river severe to erosion than deposition.

4.5.2 BSTEM Stability and Over toping on bank edge

As discussed, earlier Mersa river bank were stable against failure since its factor of safety greater than one and no erosion in toe of the bank except at reach 33 on right bank and 26 on left bank. This was due to Particle size composition of channel bank were dominated by gravel which were non-cohesive and helps that toe of bank can't erode easily in response to flow. Therefore, no need of any mitigation measure on the bank.

Even if the bank were stable against erosion due to its material composition there was also overflowing on the bank top edge. Some of the Mersa river reach not accommodate the 50year and 100 year return period design discharge on both right and left river reach this was due to small bank height or its successive reach bank height condition which lead over toping on the bank, the other condition were the bank height left or right small and the opposite were very high the flooding will happen on the bank

which had small height. Totally not only at all but at some Mersa river reach sever to flooding and thus must be mitigated.

4.6 Recommended stabilization Measures

Channel stabilization aim is to establish the river non-erosive and non-deposited. Natural or artificial stabilization measure will be practiced for channel stabilizing. According to [27] channel stabilizing naturally by adjusting channel longitudinal slope and channel cross section to keep the equilibrium between sediment supply and sediment transport. Channel stabilization artificially refers to the structural measures which are taken to improve a channel bed and bank additionally. It is an important component in the prevention and mitigation of flood control [40].

Channel stabilization artificially will establish with appropriate hydraulic structure construction. The structure made from different material such as woods or timbers, stone/masonry, concrete, geotextile depending on cost and availability of materials. This stabilization measures can be chosen by taking account the following considerations.

1. Availability of construction material and cost: These constraints are construction material availability and accessibility to the site while budget constraints include labor/ construction and maintenance cost.
2. River Engineering considerations: The flow condition, the strength of structure and influence on the river roughness and channel volume or capacity shall be taken in to account.
3. Stabilization structure environmental impact: The adverse effect of the river training structure on the environment shall be considered

By using the above consideration, the following stabilization measure for Mersa river reach is recommended to make the channel neither aggraded nor degraded. Normally, the stabilization structure for Mersa river can be categorized in to two, primarily *protection for flood prone area* for a river reach which highly affected by flood due to over toping above the bank and Secondly *controlling channel bed change* for reach which shows vertical bed change as a result of sediment transport.

4.6.1 Protection flood prone area with vertical gabion bank

In the vicinity of study reach availability of material like sand, gravel, stone, boulders are sufficient therefore the stabilization structure can be masonry retaining wall, concrete wall, gabion wall etc.

can be selected but due to cost vertical gabion bank is recommended. As discussed in the above session at Mersa River reach over flooding had a series adverse effect especially in the between 28 to 34 on one side by totally erode the farm land. As presented in the figure below the people lived on that side in addition to losing their agricultural area again their home is in danger.



Figure 4-32 Capture on the left people extract sand on the right flooding on the maize land

As shown in the figure left person who are living around this loss their land is extracting sand to feed themselves and right the photo shows the river water partially flow on its center the rest flow on maize land by dividing the land in to two. Since it is due to small height on this side, recommended vertical gabions banks to regulate or guide the flow to its normal flowing direction with the following dimension.

Table 4-9 Protection gabion bank on flooded reach

River reach	Length (m)	Height in m (the water surface profile at this reach at 100year peak discharge - right bank edge elevation + acceptable free board)
28-29	50	1.2

29-30	47	1.5
30-31	51	1
31-33	141	0.5
33-34	83	1.3

For the rest river reach the damage is not much as above can be training measure by planting vegetation on the top of edge bank.

4.6.2 Controlling channel bed change with check dam and drop structures

There are different channel bed training measures to control vertical river bed change which are commonly known as transversal structure. Transversal protection structures are constructed perpendicular to the flow direction and which are used to lower the river longitudinal slope in order to reduce flow velocity and protect the channel bed and banks [40]. According to [41] few importance of control structure in stabilizing a channel are: -

- ✚ Stabilizes the banks and bed of channel via decreasing river slope and velocity of flow.
- ✚ Avoids gully formation and channel bed degradation by lowering water level in regulated way
- ✚ Improves environmental quality and minimize pollution hazards
- ✚ Manages river flow line for non-erosion benefits, including fish passage, water table control, and reduced turbidity
- ✚ May deliver water source and habitat for wildlife

The material which are used for constructing grade control structure can be Riprap, concrete, sheet piling, treated lumber, soil cement, gabions, compacted earth fill, etc. Amongst the different protection structure for channel bed change the following are used in Mersa river for controlling vertical river change are described briefly as follows.

4.6.2.1 Check dam

Check dams are often constructed in succession along the watercourse to provide stabilization of the bed over long distances [42]. Channel degradation or erosion can be fixed by providing check dam and drop structure.

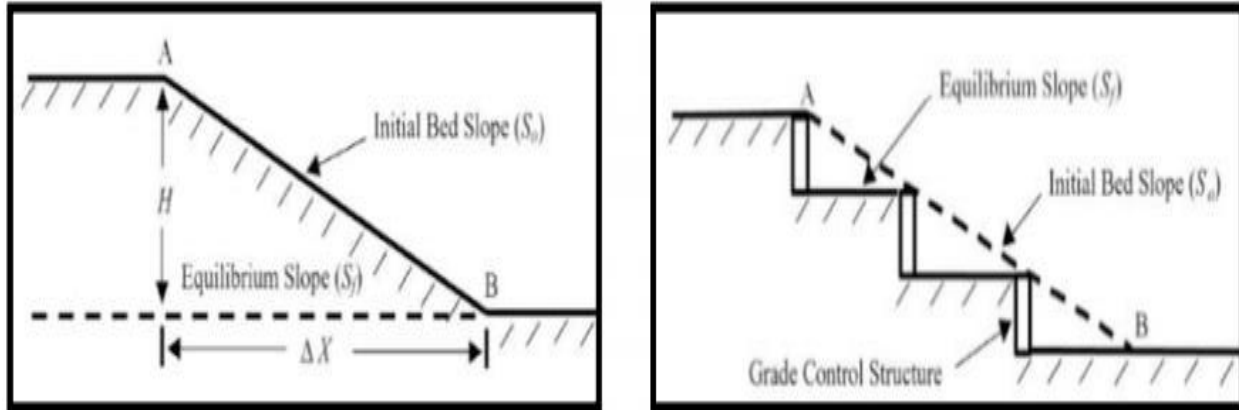


Figure 4-33 Channel slope before and after grade control structure (source from [40])

As presented in the discussion on result in Mersa river erosion is a series problem so to prevents this the transversal or stabilization structure required. For Mersa river reach having a degradation more than 2m for entire simulation period check dam is recommended to achieve the river bed control and the detail dimension is designed in the following session.

For a reach the bed become stable at which a slope is determined by formula shown below [43].

$$S_n = \frac{v(u_1)^{10/3} B^{4/3} n^2}{Q^{4/3}} \quad \text{Equation..... 4-1}$$

where S_n = stable slope

u_1 = maximum permissible velocity when erosion begin rely on size of bed material size

v = ratio between the mean velocity of water and corresponding velocity of river bottom (1.3 -1.5)

B = wetted perimeter which is considered to be equal to river width

n = manning roughness coefficient

Q = design flood discharge

The stable slope for Mersa river computed by the above equation for multiple reach which have an equal channel width since all flow data are known current flow velocity, manning roughness coefficient, channel width and maximum peak discharge and in addition the ratio 1.4, the permissible velocity for sand and gravel 1.54m/s for study reach taken.

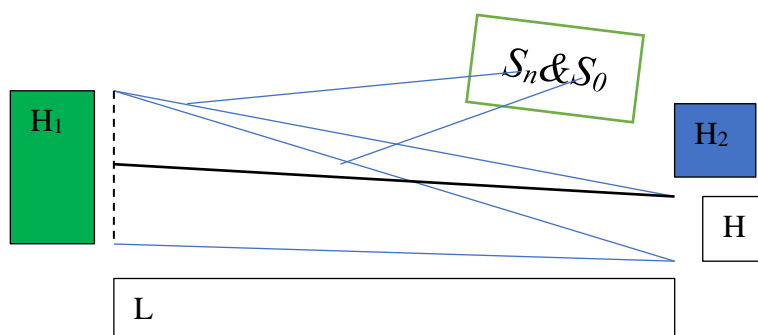


Figure 4-34 Check dam illustration

If a river reach having a longitudinal slope, S_0 is to be adopted S_n using check dam the total height of check dam is given by: -

From above figure $H_1 = S_0 * L$ and $H_2 = S_n * L$

Therefore $H = H_1 - H_2 = (S_0 * L - S_n * L) = L (S_0 - S_n)$ Equation..... 4-2

As discussed before since the check dam is recommended for channel reach having more than 2m so, the gabion check dam will be constructed on study river at reach 7, 11, 20, 23,25,28, 36, 38 and 41 (thus reach selection is from Yang sediment transport result for reach having more than 2m degradation). The detailed check dam height is determined as show in table below and for a river reach between 23 to 25 number of check dam is 2 since its length difference is too much.

Table 4-10 Height of check dam calculation

Reach	n	average width	reach length	elevation change	S_0	S_n	H(m)
41	0.08	12	70	1.55	0.022	0.0020	1.41
38	0.06	7.8	40	1.25	0.031	0.0007	1.22
36	0.05	7.5	41	1.37	0.033	0.0005	1.35
28	0.13	34	50	1.03	0.021		
25-23	0.06	7	201	4.17	0.021	0.0006	4.06
20	0.05	19	76	1.42	0.019	0.0016	1.30
11	0.05	8	41	1.58	0.039	0.0006	1.56
7	0.06	7	80	2.39	0.030	0.0006	2.34

4.6.2.2 Drop structure

Drop structure is a structure in channel to lower down the water level to prevent degradation and lowering of water level is be attended by a loss of energy of the flow. a fall or drop structure the potential energy of flow which can cause damage to downstream portion of canal is converted to kinetic energy [44].

Drops are provided with a low crest wall and can be vertical, sloping drop and. Drop structure, used when the required lowering in water level is small for maximum lowering as shown before check dam is provided for the remaining part drop structure can be provide. For study reach vertical drop structure is recommended because for degradation less than 2m and its adverse effect on channel stability is visible. finally, the drop structure will be constructed across Mersa river at reach 42 40 19 and 15 (thus reach selection is from Yang sediment transport result for reach having more than 1m degradation).

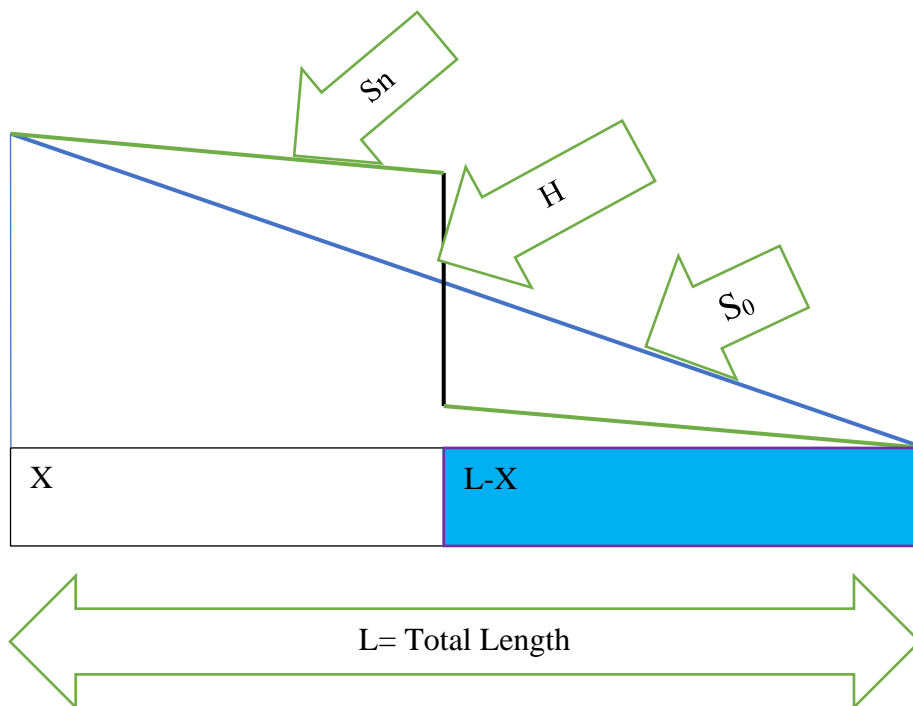


Figure 4-35 Illustration of Drop structure

H = drop height, S_n = proposed channel bed slope, S_o = existing channel bed slope, and L = length of reach

The height of drop structure is calculated by [45] $H = (S_o - S_n) L$

The proposed channel slope depends on the permissible flow velocity and can be determined by re-arranging Manning's equation as:

$$H = \left(S_o - \frac{n^2 D g F^2}{R^{4/3}} \right) L \text{ Equation..... 4-3}$$

Where n = Manning's roughness,

g = gravitational acceleration,

D = hydraulic depth

F = Froude number

R = hydraulic radius,

Detail dimension at mentioned Mersa river reach is determined in table below and all units are in SI units.

Table 4-11 Drop structure dimension

Reach	n	g	u	F	R	length	Elevation change	S ₀	S _n	H
42	0.069	9.81	1.54	0.39	1.36	62	1.21	0.02	0.007	0.78
40	0.076	9.81	1.54	0.40	1.38	66	1.43	0.02	0.009	0.73
19	0.044	9.81	1.54	0.41	1.27	67	0.98	0.02	0.003	1.12
15	0.049	9.81	1.54	0.46	1.03	65	0.52	0.02	0.005	0.95

The construction material for all stabilization structure (vertical gabion bank, check dam and drop structure) is from masonry and gabion itself since the boulders or stones are easily available and accessible in the study reach.

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Channel dynamically changes in response to the variation of flow and sediment transport. This change may cause for destruction of infrastructure, farm land and properties losses. Therefore, channel stability should assess and provided appropriate stabilization measure to prevent such damages. This study tried to cover hydrological and hydraulic analysis to investigate Mersa river bed and bank stability. L-moment diagram was used to identify best fit distribution for gauged data and out of 12 equation plotted in the diagram the recorded data fitted to General Extreme Value method (Gumbel's Method). Peak flood was estimated using General Extreme Value frequency analysis method based on 17years stream flow data and peak discharge for return period 2year, 10year,50 year and 100year is 41 m³/s,68 m³/s, 91 m³/s and 101 m³/s respectively.

Sieve analysis and Triaxial compression test were done for determining particle size gradation curve and BSTEM parameters respectively. Gradation curve was used to determine channel bank and bed material composition and in sediment transport analysis to assess channel bed change. Triaxial compression test done at 50KN, 100KN and 200KN load in laboratory and BSTEM parameters cohesion, $C=5.46\text{KPa}$ and angle of shearing resistance, $\phi=14^{\circ}$ were determined from Mohr's Circle after the result obtained from triaxial compression test drawn.

HEC-RAS model developed with having the above inputs such as design flood for steady flow analysis for water surface profile computation using direct step standard method. The result shows that there is over toping on the bank edge and adjacent area were affected due to flood.

Sediment transport simulation and BSTEM analysis were simulated to assess channel bed stability and investigate channel bank conditions. Mersa river reach exhibits both aggradation and degradation. At upper reach the maximum aggradation is 1.08m at reach 28 over entire simulation period while lower reach 2.01m at reach 9. Whereas maximum degradation, both at upper reach and lower reach is 2m at different reach for entire simulation period. The amount of sediment erosion generated from study channel is on average cumulative 22.47kt/yr. Even though both aggradation and degradation observed in Mersa River channel bed affected by erosion or degradation dominantly than aggradation and totally Mersa river channel bed is unstable.

BSTEM model analysis result shows that there was no occurred erosion on the bank toe and safety factor is greater than one except at reach 33 and 26 it can be concluded that the channel bank of Mersa river reach is stable. Generally, from Mersa river investigation the channel bed is unstable and bank is stable and the adjacent rea to the river is adversely affected by flood as analyzed in water surface profile. To minimize flood impact and for stabilizing channel bed appropriate stabilization measure are recommended. Vertical gabion bank for controlling flood in prone area, check dam and drop structure for stabilizing channel bed based on reach's degradation.

5.2 Recommendation

Based on investigation of Mersa river reach result the following recommendation can be drawn.

- ✓ The Stream flow data used for determining peak flow discharge is older than 2012 because of this design flood not actually present the current situation on the study channel.
- ✓ Sediment concentration data on the study catchment also not sufficient for usage it in sediment transport analysis without modification.
- ✓ Sand extraction for construction material on the study river reach significantly contribute to degradation and channel course change river reach to the part on which degrade.
- ✓ In triaxial compression test soil sample taken disturbed and remolded again in the laboratory but it may give best result shear strength parameter than this disturbed one. The triaxial compression test done only for UU (unconsolidated Undrained) condition, the other condition such as CU and CD done could be modify the result earned in UU.

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APPENDIX A: HYDROLOGICAL ANALYSIS

A.1 Stream flow data after quality checked

Year	Month											
	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1996	25.51	30.34	27.00	36.52	29.41	32.00	33.36	35.00	0.53	28.00	18.00	35.01
1997	23.86	18.58	36.72	23.01	26.00	35.25	29.21	31.32	33.10	27.34	28.49	39.19
1998	26.18	35.19	36.38	33.53	31.37	33.07	31.75	32.39	32.56	34.60	25.38	21.32
1999	21.27	27.26	10.01	13.01	12.13	17.02	19.27	26.29	22.30	18.51	24.26	13.29
2000	36.27	39.31	35.62	29.50	42.80	33.69	34.56	48.86	44.56	29.32	29.93	32.97
2001	35.60	29.46	22.51	33.39	32.35	39.19	36.25	37.03	32.06	38.38	28.01	41.11
2002	37.80	30.15	39.12	37.28	38.17	31.18	32.25	41.38	32.35	33.63	28.21	34.62
2003	51.85	76.08	69.38	38.00	35.96	44.54	42.84	33.28	40.26	44.01	35.89	29.84
2004	46.00	41.86	45.86	44.30	39.58	46.86	36.01	48.08	37.06	41.25	44.80	42.86
2005	51.08	56.12	59.00	62.98	39.12	56.00	35.02	38.56	39.06	41.28	33.68	35.85
2006	71.21	86.27	68.11	87.26	51.22	95.36	74.89	92.96	89.08	97.24	83.35	88.25
2007	51.37	58.38	69.35	53.51	51.76	56.18	48.25	39.25	56.82	54.13	52.12	47.13
2008	49.36	31.26	38.28	46.30	36.68	33.25	31.34	40.30	44.21	39.33	35.27	76.85
2009	65.12	54.13	61.13	63.13	59.12	46.27	31.49	67.42	31.46	68.05	52.05	46.06
2010	64.12	46.30	43.25	42.25	39.76	63.09	64.09	57.13	48.06	56.02	49.32	43.09
2011	89.09	64.25	61.08	63.26	51.14	49.36	42.36	49.42	57.58	47.21	73.28	55.25
2012	45.04	41.01	43.12	32.29	51.26	59.01	58.84	44.75	73.85	29.18	35.02	61.06

A.2 Data outlier test

Year	Maximum discharge (m ³ /sec)	Descending order	Y=log (Xi)
1996	27.56	82.10	1.914337
1997	29.34	58.61	1.767945
1998	31.14	53.78	1.730661
1999	18.72	53.19	1.725801
2000	36.45	51.37	1.710731
2001	33.78	47.87	1.68006
2002	34.68	45.65	1.659407
2003	45.16	45.16	1.654772
2004	42.88	42.88	1.63223
2005	45.65	41.87	1.621893
2006	82.10	36.45	1.561693

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2007	53.19	34.68	1.54005
2008	41.87	33.78	1.528634
2009	53.78	31.14	1.493343
2010	51.37	29.34	1.467453
2011	58.61	27.56	1.440227
2012	47.87	18.72	1.272258
mean	43.18		1.61
standard deviation	14.68657039	14.68657039	0.149224
		Maximum	1.914337
		Minimum	1.272258

A.2.1 K_n value for different sample size for outlier test (source: Subramanya, hydrology book)

No. sample	k	No. sample	k	No. sample	k	No. sample	k
10	2.0360	24	2.4670	38	2.6610	60	2.8370
11	2.0880	25	2.4860	39	2.6710	65	2.8660
12	2.1340	26	2.5020	40	2.6820	70	2.8930
13	2.1750	27	2.5190	41	2.6920	75	2.9170
14	2.2130	28	2.5340	42	2.7000	80	2.9400
15	2.2470	29	2.5490	43	2.7100	85	2.9610
16	2.2790	30	2.5630	44	2.7190	90	2.9810
17	2.3090	31	2.5770	45	2.7270	95	3.0000
18	2.3350	32	2.5910	46	2.7360	100	3.0170
19	2.3610	33	2.6040	47	2.7440	110	3.0490
20	2.3850	34	2.6160	48	2.7530	120	3.0780
21	2.4080	35	2.6280	49	2.7600	130	3.1040
22	2.4290	36	2.6390	50	2.7680	140	3.1290
23	2.4480	37	2.6500	55	2.8040		

A.3 Table calculation for Gumbel method

$$X_T = \bar{X} + K * \sigma n$$

Where: -

$$\sigma n \text{ the standard deviation of sample of size of N: } \sigma n = \sqrt{\frac{\sum(X-\bar{X})^2}{N-1}}$$

K - Frequency factor expressed as

$$K = \frac{Y_T - Y_n}{S_n}$$

Y_T = reduced variant, a function of T and is given by

$$Y_T = -[\ln * \ln \left(\frac{T}{T-1} \right)]$$

Or $Y_T = -[0.834 + 2.303 \log * \log \left(\frac{T}{T-1} \right)]$

$Y_n = 0.5181$ for sample N = 17

$S_n = 1.0411$ for sample N=17

Year	Q (m ³ /s)	Descending order Q(m ³ /s)	Q-Qava(m ³ /s)	(Q-Qava) ² (m ³ /s)
1996	27.56	82.10	39.10	1528.725285
1997	29.34	58.61	15.61	243.5576401
1998	31.14	53.78	10.78	116.3144275
1999	18.72	53.19	10.19	103.7647823
2000	36.45	51.37	8.37	70.09875625
2001	33.78	47.87	4.87	23.71284184
2002	34.68	45.65	2.65	7.00396225
2003	45.16	45.16	2.16	4.673883674
2004	42.88	42.88	-0.12	0.01498584
2005	45.65	41.87	-1.13	1.279161
2006	82.10	36.45	-6.55	42.90795851
2007	53.19	34.68	-8.32	69.26123211
2008	41.87	33.78	-9.22	85.045284
2009	53.78	31.14	-11.86	140.6180931
2010	51.37	29.34	-13.66	186.6092603
2011	58.61	27.56	-15.44	238.4965444
2012	47.87	18.72	-24.28	589.619571
sum	734.1348333	734.1348333	3.134833333	$\Sigma(Q-Qava)^2 = 3451.703669$
mean	$\bar{X} = 43$	standard deviation		15

A.3.1 The result due to Gumbel's Method as shown below

	Return Period (year)			
	2	10	50	100
Y_T	0.367	2.250	3.902	4.600
k	-0.146	1.664	3.250	3.921
$X_T = Q_T$ (m ³ /s)	41.046	67.621	90.919	100.769

A.3.2 Table for Reduced mean Y_n in Gumbel's Extreme Value Distribution (Subramanya, hydrology book)

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Sample size,N	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
10	0.49520	0.49960	0.50350	0.50700	0.51000	0.51280	0.51570	0.51810	0.52020	0.52200
20	0.52360	0.52520	0.52680	0.52830	0.52960	0.53090	0.53200	0.53320	0.53430	0.53530
30	0.53620	0.53710	0.53800	0.53880	0.53960	0.54020	0.54100	0.54180	0.54240	0.54300
40	0.54360	0.54420	0.54480	0.54530	0.54580	0.54630	0.54680	0.54730	0.54770	0.54810
50	0.54850	0.54890	0.54930	0.54970	0.55010	0.55040	0.55080	0.55110	0.55150	0.55180
60	0.55210	0.55240	0.55270	0.55300	0.55330	0.55350	0.55380	0.55400	0.55430	0.55450
70	0.55480	0.55500	0.55520	0.55550	0.55570	0.55590	0.55610	0.55630	0.55650	0.55670
80	0.55690	0.55700	0.55720	0.55740	0.55760	0.55780	0.55800	0.55810	0.55830	0.55850
90	0.55860	0.55870	0.55890	0.55910	0.55920	0.55930	0.55950	0.55960	0.55980	0.55990
100	0.5600									

A.3.3 Table for Reduced Standard Deviation S_n in Gumbel's Extreme Value Distribution

Sample size,N	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
10	0.94960	0.96970	0.98330	0.99710	1.00950	1.02060	1.03160	1.04110	1.04930	1.05650
20	1.06280	1.10960	1.07540	1.08110	1.08640	1.09150	1.09610	1.10040	1.10470	1.10860
30	1.11240	1.11590	1.11930	1.12260	1.12550	1.12850	1.13130	1.13390	1.13630	1.13880
40	1.14130	1.14360	1.14580	1.14800	1.14990	1.15190	1.15380	1.15570	1.15740	1.15900
50	1.16070	1.16230	1.16380	1.16580	1.16670	1.16810	1.16960	0.17080	1.17210	1.17340
60	1.17470	1.17590	1.17700	1.17820	1.17930	1.18030	1.18140	1.18240	1.18340	1.18440
70	1.18540	1.18630	1.18730	1.18810	1.18900	1.18980	1.19060	1.19150	1.19230	1.19300
80	1.19380	1.19450	1.19530	1.19590	1.19670	1.19730	1.19800	1.19870	1.19940	1.20010
90	1.20070	1.20130	1.20200	1.20260	1.20320	1.20380	1.20440	1.20490	1.20550	1.20600
100	1.2065									

A.4. Table calculation for log Pearson type III Distribution Method

Year	Q (m ³ /s)	Descending Q (m ³ /s)	Z=logx	(z-zmean)	(z-zmean) ²	(z-zmean) ³
1996	27.56	82.10	1.914	0.302	0.091	0.028
1997	29.34	58.61	1.768	0.156	0.024	0.004
1998	31.14	53.78	1.731	0.119	0.014	0.002
1999	18.72	53.19	1.726	0.114	0.013	0.001
2000	36.45	51.37	1.711	0.099	0.010	0.001
2001	33.78	47.87	1.680	0.068	0.005	0.000
2002	34.68	45.65	1.659	0.048	0.002	0.000
2003	45.16	45.16	1.655	0.043	0.002	0.000
2004	42.88	42.88	1.632	0.020	0.000	0.000
2005	45.65	41.87	1.622	0.010	0.000	0.000
2006	82.10	36.45	1.562	-0.050	0.003	0.000
2007	53.19	34.68	1.540	-0.072	0.005	0.000
2008	41.87	33.78	1.529	-0.083	0.007	-0.001
2009	53.78	31.14	1.493	-0.119	0.014	-0.002
2010	51.37	29.34	1.467	-0.144	0.021	-0.003

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2011	58.61	27.56	1.440	-0.172	0.029	-0.005
2012	47.87	18.72	1.272	-0.340	0.115	-0.039
mean	43	43	1.61			
sum					0.356	-0.014
Standard deviation					0.149	
Ca						-0.0066

A.4.1 Table calculation coefficient skew variety for different return period

interpolate for our Ca=-0.0066

Ca	2	10	25	50	100	200	1000
0	0	1.282	1.751	2.054	2.326	2.576	3.09
-0.1	0.017	1.27	1.716	2	2.252	2.482	2.95
-0.0066	0.0112		1.7487	2.0504	2.3211		

A.4.2 The result due to Log Pearson type III Method as shown below

	Return period (year)		
	2	50	100
Ca	-0.0066	-0.0066	-0.0066
Kz	0.0112	2.0504	2.3211
Z _T	1.61353	1.91783	1.95822
X _T = Q _T (m ³ /s)	41.07020	82.76108	90.82763

A.4.3 K_z = F(C_a, T) for use in Log-Pearson Type III Distribution (Subramanya, hydrology book)

Coef.of skew, C _a	Return Period T in years				
	2	10	25	50	100
3.0	-0.396	1.180	2.278	3.152	4.051
2.5	-0.360	1.250	2.262	3.048	3.845
2.2	-0.330	1.284	2.240	2.970	3.705
2.0	-0.307	1.302	2.219	2.912	3.605
1.8	-0.282	1.318	2.193	2.848	3.499
1.6	-0.254	1.329	2.163	2.780	3.388
1.4	-0.225	1.337	2.128	2.706	3.271
1.2	-0.195	1.340	2.087	2.626	3.149
1.0	-0.164	1.340	2.043	2.542	3.022
0.9	-0.148	1.339	2.018	2.498	2.957
0.8	-0.132	1.336	1.998	2.453	2.891
0.7	-0.116	1.333	1.967	2.407	2.824

0.6	-0.099 1.328 1.939 2.359 2.755
0.5	-0.083 1.323 1.910 2.311 2.686
0.4	-0.066 1.317 1.880 2.261 2.615
0.3	-0.050 1.309 1.849 2.211 2.544
0.2	-0.033 1.301 1.818 2.159 2.472
0.1	-0.017 1.292 1.785 2.107 2.400
0.0	0.000 1.282 1.751 2.054 2.326
-0.1	0.017 1.270 1.716 2.000 2.252
-0.2	0.033 1.258 1.680 1.945 2.178
-0.3	0.050 1.245 1.643 1.890 2.104
-0.4	0.066 1.231 1.606 1.834 2.029
-0.5	0.083 1.216 1.567 1.777 1.955
-0.6	0.099 1.200 1.528 1.720 1.880
-0.7	0.116 1.183 1.488 1.663 1.806
-0.8	0.132 1.166 1.448 1.606 1.733
-0.9	0.148 1.147 1.407 1.549 1.660
-1.0	0.164 1.128 1.366 1.492 1.588
-1.4	0.225 1.041 1.198 1.270 1.318
-1.8	0.282 0.945 1.035 1.069 1.087
-2.2	0.330 0.844 0.888 0.900 0.905
-3.0	0.396 0.660 0.666 0.666 0.667

A.5 Table calculation for Lognormal distribution Method

Year	Q (m ³ /s)	Descending Q (m ³ /s)	Z=logx	Z-Zmean	(Z-Zmean) ²
1996	27.56	82.10	1.914	0.304	0.092621269
1997	29.34	58.61	1.768	0.158	0.024946481
1998	31.14	53.78	1.731	0.121	0.014558956
1999	18.72	53.19	1.726	0.116	0.013409967
2000	36.45	51.37	1.711	0.101	0.010146674
2001	33.78	47.87	1.680	0.070	0.004908354
2002	34.68	45.65	1.659	0.049	0.002441099
2003	45.16	45.16	1.655	0.045	0.002004565
2004	42.88	42.88	1.632	0.022	0.000494186
2005	45.65	41.87	1.622	0.012	0.000141434
2006	82.10	36.45	1.562	-0.048	0.002333608

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2007	53.19	34.68	1.540	-0.070	0.004893021
2008	41.87	33.78	1.529	-0.081	0.006620437
2009	53.78	31.14	1.493	-0.117	0.013608852
2010	51.37	29.34	1.467	-0.143	0.02031973
2011	58.61	27.56	1.440	-0.170	0.028822979
2012	47.87	18.72	1.272	-0.338	0.11406999
mean	43	43	1.61	0.002	
sum					0.356341604
		Standard deviation			0.149

A.5.1 The result by Lognormal distribution Method as shown below

	Return Period (year)		
	2	50	100
Ca	0	0	0
Kz	0.000	2.054	2.326
Z _T	1.61185	1.91836	1.95895
X _T = Q _T (m ³ /s)	40.91217	82.86249	90.98018

A.6 Table calculation for l-moment ratio diagram

Table to determine the value of LCS (measure of skewness) and LCK (measure of kurtosis)

Year	Qmax	Descending (X)	Rank (i)	$F_i = (i-0.35)/N$	$[F_i]^2$	$[F_i]^3$	$[F_i]^4$	X*F _i	X*[F _i] ²	X*[F _i] ³	X*[F _i] ⁴
1996	27.56	82.10	17	0.979	0.959	0.939	0.920	80.409	78.753	77.132	75.544
1997	29.34	58.61	16	0.921	0.847	0.780	0.718	53.952	49.668	45.724	42.093
1998	31.14	53.78	15	0.862	0.743	0.640	0.552	46.350	39.943	34.421	29.663
1999	18.72	53.19	14	0.803	0.645	0.518	0.416	42.706	34.290	27.533	22.107
2000	36.45	51.37	13	0.744	0.554	0.412	0.307	38.227	28.446	21.167	15.751
2001	33.78	47.87	12	0.685	0.470	0.322	0.221	32.805	22.481	15.406	10.558
2002	34.68	45.65	11	0.626	0.392	0.246	0.154	28.596	17.915	11.223	7.031
2003	45.16	45.16	10	0.568	0.322	0.183	0.104	25.636	14.552	8.261	4.689
2004	42.88	42.88	9	0.509	0.259	0.132	0.067	21.817	11.101	5.648	2.874
2005	45.65	41.87	8	0.450	0.203	0.091	0.041	18.841	8.478	3.815	1.717
2006	82.10	36.45	7	0.391	0.153	0.060	0.023	14.258	5.577	2.182	0.853
2007	53.19	34.68	6	0.332	0.110	0.037	0.012	11.525	3.830	1.273	0.423
2008	41.87	33.78	5	0.274	0.075	0.020	0.006	9.239	2.527	0.691	0.189
2009	53.78	31.14	4	0.215	0.046	0.010	0.002	6.686	1.436	0.308	0.066
2010	51.37	29.34	3	0.156	0.024	0.004	0.001	4.574	0.713	0.111	0.017
2011	58.61	27.56	2	0.097	0.009	0.001	0.000	2.675	0.260	0.025	0.002
2012	47.87	18.72	1	0.038	0.001	0.000	0.000	0.716	0.027	0.001	0.000
mean	43.184							25.824	18.899	15.091	12.563
sum	734.13							439.012	320.00	254.92	213.58
b0	M1	43.184		λ ₁	43.184						
b1	M2	25.824		λ ₂	8.464	LCV	T	0.195998518			
b2	M3	18.899		λ ₃	1.634	LCS	τ ₃	0.193052930			
b3	M4	15.091		λ ₄	1.554	LCK	τ ₄	0.183601134			
b4	M5	12.563									

APPENDIX B: GEOMETRIC DATA

B.1: River Cross Section Data

River station		left side (LOB)				channel					right side (ROB)					
42	station	49838.36	49839.6	49840.5	49841.6	49842	49843.7	49847.4	49848.7	49854.5	49859.9	49861.6	49862.9	49863.2	49865	
	elevation	1782	1782	1778.92	1778.13	1777.83	1777.37	1777.75	1776.98	1777.24	1777.68	1778.24	1779.25	1780.26	1780.26	
41	station	49870.69	49871.6	49872.7	49873.9	49875.5	49880.3	49883.3	49883.9	49885	49885.6	49886.5				
	elevation	1779	1779	1778.9	1776.0	1775.8	1775.8	1775.9	1776.0	1776.0	1778.8	1778.8				
40	station			49890.2	49892.2	49894.1	49896.4	49898.1	49905	49914.4	49920.4	49922.5	49924.6			
	elevation			1778.52	1778.69	1775.12	1774.65	1774.21	1774.34	1774.65	1774.97	1777	1777.54			
39	station	49932.5	49934.8	49936.1	49938.7	49941	49942.1	49945.2	49945.7	49947.5	49948.2					
	elevation	1777.89	1777.87	1773.8	1772.78	1772.96	1773.49	1773.28	1774.4	1777.52	1777.6					
38	station			49976.6	49977.5	49978.2	49980.8	49983.9	49984.4	49984.7	49985.7					
	elevation			1773.59	1773.34	1772.6	1771.87	1772.16	1772.95	1773.05	1775.46					
37	station			50014.3	50014.9	50017.9	50020	50025.4	50036.5	50044.1	50047	50048.6	50049.4			
	elevation			1773.7	1773.55	1772.22	1770.92	1770.62	1771.14	1771.34	1771.33	1771.98	1775.36			
36	station	50088.9	50089.63	50090.2	50091.2	50091.9	50092.6	50093.9	50094.9	50095	50095.4	50096.6	50096.8	50097	50098.3	50099.4
	elevation	1773.58	1770.568	1770.46	1769.57	1769.01	1768.73	1769.21	1769.71	1768.99	1768.51	1768.96	1769.17	1769.28	1774.43	1774.57
35	station			50128.57	50131.3	50133.6	50135.4	50137.4	50140.7	50143	50143.3	50143.8	50144.9	50146.6		
	elevation			1769.59	1769.6	1769.42	1768.1	1768.15	1767.51	1767.06	1767.27	1767.9	1768.57	1771.68		
34	station			50175.8	50180.9	50184.5	50198.5	50204.2	50227.3	50229.8	50231.8					
	elevation			1768.14	1768.04	1767.05	1766.66	1765.79	1765.87	1766.36	1766.57					
33	station			50205.7	50216.1	50228.4	50234.2	50238.7	50243.1	50255.1	50268.7	50276.6	50278.3			
	elevation			1766.23	1765.48	1765.63	1764.72	1764.21	1764.32	1764.47	1764.61	1764.65	1765.7			
32	station			50220.52	50224.4	50232.7	50240.4	50255.2	50270.6	50279.8	50291.6	50308.1	50313.7	50315.3		
	elevation			1766.964	1766.98	1764.12	1763.53	1763.25	1762.63	1762.96	1762.54	1763.06	1762.95	1763.85		

32	station	50220.52	50224.4	50232.7	50240.4	50255.2	50270.6	50279.8	50291.6	50308.1	50313.7	50315.3												
	elevation	1766.964	1766.98	1764.12	1763.53	1763.25	1762.63	1762.96	1762.54	1763.06	1762.95	1763.85												
31	station			50260.5	50264.6	50269.9	50276.1	50285.7	50291.9	50299.5	50313.3	50317.6	50324.3	50331.1	50335.3	50339.7	50342.2							
	elevation			1764.69	1764.7	1762.55	1761.18	1761.49	1761.35	1761.36	1762.05	1761.68	1761.85	1761.72	1762.29	1762.74	1762.7							
30	station			50295.6	50300	50300.6	50305.4	50316.3	50325.9	50329.5	50331.5	50337.2	50348.8	50353	50359.8	50363.4	50377	50379.9	50382.2					
	elevation			1764.85	1764.8	1759.98	1760.27	1760.25	1760.33	1760.77	1760.11	1760.04	1760.09	1760.35	1760.06	1760.55	1760.51	1760.52	1760.57					
29	station	50324.7	50326.91	50332.2	50338.9	50343.4	50348.1	50350.2	50350.2	50354	50355.6	50360.1	50367.8	50369.4	50376.9	50383.7	50386	50392	50396.9	50400.6	50404	50408.2	50412.7	
	elevation	1764.59	1764.587	1763.54	1758.64	1758.35	1758.53	1758.25	1758.27	1758.44	1758.79	1758.45	1759.01	1758.88	1758.57	1758.89	1759.26	1758.77	1758.5	1759.32	1758.6	1758.57	1759.6	1759.58
28	station	50402	50402.84	50403.1	50403.6	50405.6	50406.9	50407.6	50410.3	50412.6	50415.7	50418.7	50420.3	50422.3	50424.2	50426.2	50430.1	50431.6	50438.2	50439.8	50440.2	50441.6	50442.3	50443.5
	elevation	1766.26	1766.243	1766.91	1759.64	1756.4	1756.57	1757.45	1757.29	1757.36	1757.63	1757.6	1757.2	1757.17	1757.07	1756.87	1756.72	1757.11	1759.82	1759.63	1759.53	1759.52	1759.53	1759.53
27	station			50451.44	50452.1	50452.1	40453	50457.6	50460	50461.1	50462.1	50463.6	50464	50465.3	50466.1	50468.5								
	elevation			1762.652	1762.57	1761.14	1758.65	1755.37	1756.28	1755.96	1755.89	1756.53	1756.2	1756.22	1759.67	1759.69								
26	station	50455.7	50457.46	50459.3	50461	50462.8	50464.6	50466.4	50468.2	50470	50471.7	50473.5	50475.3	50477.1	50478.9	50480.7	50482.4	50484.2	50485	50485.1	50485.3	50487.4		
	elevation	1758.88	1758.864	1757.94	1753.31	1753.3	1752.82	1752.24	1752.27	1752.24	1752.01	1751.53	1751.84	1751.75	1751.72	1751.94	1752.03	1752.36	1754.77	1754.99	1758.53	1758.62		
25	station	50564.2	50564.78	50565	50565.4	50566.2	50568.5	50570	50570.9	50570.9	50572.3	50573.6												
	elevation	1759.24	1759.356	1753.79	1753.24	1753	1753.49	1752.92	1754.07	1753.31	1758.47	1758.68												

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		left side (LOB)			channel				right side (ROB)						
25	station	50564.2	50564.78	50565	50565.4	50566.2	50568.5	50570	50570.9	50570.9	50572.3	50573.6			
	elevation	1759.24	1759.356	1753.79	1753.24	1753	1753.49	1752.92	1754.07	1753.31	1758.47	1758.68			
24		left side (LOB)			channel				right side (ROB)						
	station	50613.24	50615.9	50617.2	50617.2	50617.6	50618.2	50618.5	50619	50620	50621.4	50623.3	50625.9	50626.5	50628.7
23	elevation	1752.986	1751.89	1751.59	1751.59	1751.98	1752.22	1751.99	1751.61	1751.96	1752.15	1751.9	1759.33	1759.46	1759.31
		left side (LOB)			channel				right side (ROB)						
22	station	50675.4	50676.41	50677.9	50678.1	50678.8	50679.2	50679.4	50680	50680.9	50681.8	50682.2	50684.6		
	elevation	1752.25	1752.246	1750.8	1750.61	1750.54	1750.35	1750.29	1750.87	1751.16	1751.03	1758.36	1758.35		
21		left side (LOB)			channel				right side (ROB)						
	station	50733.27	50734.9	50735.4	50735.7	50739.8	50739.9	50745	50746.1	50747.3	50748.6	50750.3			
20	elevation	1751.23	1749.98	1748.75	1748.75	1748.84	1749.04	1748.96	1749.27	1750.55	1755.37	1755.32	1755.33		
		left side (LOB)			channel				right side (ROB)						
19	station	50782.54	50785.9	50789.2	50792.1	50793.7	50799.6	50802	50803.6						
	elevation	1748.984	1748.97	1747.83	1747.97	1747.71	1748.04	1751.78	1751.77						
18		left side (LOB)			channel				right side (ROB)						
	station	50833.7	50834.34	50835.7	50837.4	50839.3	50847.4	50851.5	50856.8	50857					
17	elevation	1751.79	1751.764	1751.76	1746.63	1746	1746.32	1746.56	1746.04	1748.6					
		left side (LOB)			channel				right side (ROB)						
16	station	50857.2	50857.39	50857.4	50864.2	50866.5	50868.2	50875.4	50880.3	50882.6	50884.8				
	elevation	1747.99	1747.978	1745.36	1745.18	1744.85	1744.52	1744.96	1745.13	1747.96	1747.95				
15		left side (LOB)			channel				right side (ROB)						
	station	50897.7	50898.26	50899.1	50899.8	50900.9	50903.6	50905.5	50908.6	50912.1	50912.3	50912.3			
14	elevation	1746.84	1746.851	1744.13	1743.75	1743.53	1743.62	1743.78	1743.99	1744.17	1747.36	1747.35			
		left side (LOB)			channel				right side (ROB)						
13	station	50994.8	50996.83	50998.1	51001.7	51005.4	51008.6	51009.7	51017.2	51025.1	51026.7				
	elevation	1743.73	1742.066	1741.56	1741.41	1741.87	1741.64	1741.04	1741.28	1744.05	1744.05				
12		left side (LOB)			channel				right side (ROB)						
	station	51091.47	51092.8	51093.2	51094.2	51096.3	51098.9	51101.7							
11	elevation	1742.985	1742.98	1739.22	1739	1738.83	1738.96	1739.02							
		left side (LOB)			channel				right side (ROB)						
10	station	51175.4	51176.49	51178	51178.1	51179.6	51183.4	51183.8	51192.2	51193.7	51197.6	51201.3			
	elevation	1741.02	1741.036	1741.03	1739.57	1736.96	1739.01	1737.26	1737.03	1736.84	1736.62	1740.01			
9		left side (LOB)			channel				right side (ROB)						
	station	51208.2	51209.72	51210.2	51212.8	51220.6	51229.2	51237.6	51244.3	51247.6	51249.3				
8	elevation	1738.62	1738.597	1736.84	1736.14	1736.13	1736.1	1736.08	1735.83	1736.42	1736.9				
		left side (LOB)			channel				right side (ROB)						

		left side (LOB)			channel				right side (ROB)						
13	station	51295.6	51298.32	51300.1	51301.6	51305.7	51311.7	51323.2	51325.5	51329	51331.6	51333.1			
	elevation	1735.82	1735.803	1734.56	1733.77	1734.12	1733.54	1733.64	1733.8	1734.89	1735.65	1735.64			
12		left side (LOB)			channel				right side (ROB)						
	station	51392.5	51394.63	51396	51397.8	51398.9	51402.2	51403.5	51406.9	51410.1	51412.2	51414.6			
11	elevation	1735.97	1735.956	1732.57	1731.33	1731.67	1731.34	1731.91	1731.72	1732.47	1735.03	1735.02			
		left side (LOB)			channel				right side (ROB)						
10	station	51452.69	51454.7	51455.4	51456.4	51457.1	51457.4	51457.7	51462.9	51462.9					
	elevation	1731.976	1730.87	1730.37	1730.53	1730.25	1731.68	1732.24	1732.55						
9		left side (LOB)			channel				right side (ROB)						
	station	51512.5	51513.27	51515	51516.2	51518.4	51520.8	51522.9	51526.9	51534.4	51535.4	51537			
8	elevation	1732.64	1732.642	1731.23	1729.08	1728.97	1729.03	1729.06	1728.95	1731.43	1732.01	1732.02			
		left side (LOB)			channel				right side (ROB)						
7	station	51612.98	51613.6	51614.2	51616.3	51618.4	51620.3	51622.6							
	elevation	1722.956	1721.55	1720.1	1720.38	1720.36	1721.37	1721.78							
6		left side (LOB)			channel				right side (ROB)						
	station	51688.32	51690.9	51693	51695.4	51698.3	51700								
5	elevation	1719.748	1719.24	1718.69	1718.8	1718.62	1719.72								
		left side (LOB)			channel				right side (ROB)						
4	station	51770.3	51771.9	51774.5	51774.6	51776.6	51776.6	51776.6	51777.6	51779.2	51779.2				
	elevation	1717.98	1717.17	1717.19	1717.19	1716.88	1717.08								
3		left side (LOB)			channel				right side (ROB)						
	station	51851.2	51852.9	51855.6	51858.4	51858.5	51860.1	51861.7							
2	elevation	1715.54	1714.97	1715.26	1714.8	1715.02	1715.44	1716.14							
		left side (LOB)			channel				right side (ROB)						
1	station	51973.3	51973.8	51976	51977.5	51981.8	51985.6	51987.2	51989.7						
	elevation	1714.17	1713.07	1712.32	1712.85	1712.7	1714.37	1716.57	1716.54						
1		left side (LOB)			channel				right side (ROB)						
	station	52062.8	52069.5	52074.6	52084.7	52087.6	52089.6	52090.2							
1	elevation	1711.49	1710.35	1709.99	1710.09	1711.52	1713.83	1713.82							
		left side (LOB)			channel				right side (ROB)						
1	station	52170.9	52172.4	52174.8	52175.7	52178.4	52182.5								
	elevation	1708.32	1707.44	1707.87	1708.18	1707.81	1708.27								
1		left side (LOB)			channel				right side (ROB)						
	station	52271.6	52271.9	52272.2	52274	52274.8	52275.1	52275.3							
1	elevation	1706.392	1706.17	1706.02	1706.17	1705.97	1706.24	1706.41							
		left side (LOB)			channel				right side (ROB)						
1	station	52353.93	52356.4	52359.8	52365.4	52367.6	52369.2								
	elevation	1703.662	1703.25	1703.19	1703.41	1703.42	1703.76								

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B.2: manning roughness coefficient estimation by French and chow

reach	right river bank (ROB)						n	left river bank (LOB)						n	river bed (channel)						n
	no	n1	n2	n3	n4	m5		no	n1	n2	n3	n4	m5		no	n1	n2	n3	n4	m5	
42	0.019	0.01	0.013	0.022	0.007	1	0.071	0.018	0.01	0.013	0.022	0.007	1	0.07	0.018	0.005	0.013	0.02	0.007	1	0.065
41	0.019	0.02	0.005	0.011	0.015	1.15	0.0805	0.018	0.02	0.005	0.011	0.015	1.15	0.0794	0.018	0.02	0.005	0.01	0.005	1.15	0.0679
40	0.019	0.01	0.014	0.016	0.023	1	0.082	0.018	0.01	0.014	0.016	0.023	1	0.081	0.018	0.01	0.014	0.02	0.008	1	0.066
39	0.019	0.01	0.012	0.014	0.011	1	0.066	0.018	0.01	0.012	0.014	0.011	1	0.065	0.018	0.01	0.012	0.01	0.006	1	0.06
38	0.019	0.01	0.005	0.015	0.012	1	0.061	0.018	0.01	0.005	0.015	0.012	1	0.06	0.018	0.01	0.005	0.02	0.009	1	0.057
37	0.019	0.01	0.005	0.01	0.006	1	0.05	0.018	0.01	0.005	0.01	0.006	1	0.049	0.018	0.01	0.005	0.01	0.007	1	0.05
36	0.019	0.005	0.005	0.011	0.013	1	0.053	0.018	0.005	0.005	0.011	0.013	1	0.052	0.018	0.005	0.005	0.01	0.01	1	0.049
35	0.019	0.01	0.005	0.01	0.007	1	0.051	0.018	0.01	0.005	0.01	0.007	1	0.05	0.018	0.01	0.005	0.01	0.007	1	0.05
34	0.019	0.01	0.005	0.012	0.006	1	0.052	0.018	0.01	0.005	0.012	0.006	1	0.051	0.018	0.01	0.005	0.01	0.006	1	0.051
33	0.019	0.005	0.005	0.014	0.008	1	0.051	0.018	0.005	0.005	0.014	0.008	1	0.05	0.018	0.005	0.005	0.01	0.008	1	0.05
32	0.019	0.005	0.005	0.015	0.009	1	0.053	0.018	0.005	0.005	0.015	0.009	1	0.052	0.018	0.005	0.005	0.02	0.009	1	0.052
31	0.019	0.005	0.005	0.011	0.01	1	0.05	0.018	0.005	0.005	0.011	0.01	1	0.049	0.018	0.005	0.005	0.01	0.01	1	0.049
30	0.019	0.01	0.005	0.013	0.012	1	0.059	0.018	0.01	0.005	0.013	0.012	1	0.058	0.018	0.01	0.005	0.01	0.012	1	0.058
29	0.019	0.01	0.005	0.012	0.006	1	0.052	0.018	0.01	0.005	0.012	0.006	1	0.051	0.018	0.01	0.005	0.01	0.006	1	0.051
28	0.019	0.01	0.005	0.028	0.05	1.15	0.1288	0.018	0.01	0.005	0.028	0.05	1.15	0.1277	0.018	0.01	0.005	0.03	0.05	1.15	0.1277
27	0.019	0.02	0.005	0.06	0.01	1.15	0.1311	0.018	0.02	0.005	0.06	0.01	1.15	0.13	0.018	0.02	0.005	0.06	0.01	1.15	0.13

	n0	n1	n2	n3	n4	m5	n		n1	n2	n3	n4	m5	n		n1	n2	n3	n4	m5	n
26	0.019	0.01	0.005	0.06	0.006	1	0.1	0.016	0.01	0.005	0.06	0.006	1	0.097	0.018	0.01	0.005	0.06	0.006	1	0.099
25	0.019	0.005	0.005	0.012	0.025	1	0.066	0.016	0.005	0.005	0.012	0.025	1	0.063	0.018	0.005	0.005	0.01	0.015	1	0.055
24	0.019	0.005	0.005	0.015	0.016	1	0.06	0.016	0.005	0.005	0.015	0.016	1	0.057	0.018	0.005	0.005	0.02	0.016	1	0.059
23	0.019	0.01	0.005	0.01	0.008	1	0.052	0.016	0.01	0.005	0.01	0.008	1	0.049	0.018	0.01	0.005	0.01	0.008	1	0.051
22	0.019	0.005	0.005	0.011	0.006	1	0.046	0.016	0.005	0.005	0.011	0.006	1	0.043	0.018	0.005	0.005	0.01	0.006	1	0.045
21	0.019	0.01	0.005	0.021	0.005	1	0.06	0.016	0.01	0.005	0.021	0.005	1	0.057	0.018	0.01	0.005	0.02	0.005	1	0.059
20	0.019	0.005	0.005	0.015	0.007	1	0.051	0.016	0.005	0.005	0.015	0.007	1	0.048	0.018	0.005	0.005	0.02	0.007	1	0.05
19	0.019	0.005	0.005	0.01	0.006	1	0.045	0.016	0.005	0.005	0.01	0.006	1	0.042	0.018	0.005	0.005	0.01	0.006	1	0.044
18	0.019	0.005	0.005	0.012	0.008	1	0.049	0.016	0.005	0.005	0.012	0.008	1	0.046	0.018	0.005	0.005	0.01	0.008	1	0.048
17	0.019	0.01	0.005	0.02	0.01	1	0.064	0.016	0.01	0.005	0.02	0.01	1	0.061	0.018	0.01	0.005	0.02	0.01	1	0.063
16	0.019	0.005	0.005	0.01	0.009	1	0.048	0.016	0.005	0.005	0.01	0.009	1	0.045	0.018	0.005	0.005	0.01	0.009	1	0.047
15	0.019	0.005	0.005	0.015	0.006	1	0.05	0.016	0.005	0.005	0.015	0.006	1	0.047	0.018	0.005	0.005	0.02	0.006	1	0.049
14	0.019	0.01	0.005	0.013	0.008	1	0.055	0.016	0.01	0.005	0.013	0.008	1	0.052	0.018	0.01	0.005	0.01	0.008	1	0.054
13	0.019	0.005	0.005	0.01	0.01	1	0.049	0.016	0.005	0.005	0.01	0.01	1	0.046	0.018	0.005	0.005	0.01	0.01	1	0.048
12	0.019	0.005	0.005	0.012	0.01	1	0.051	0.016	0.005	0.005	0.012	0.01	1	0.048	0.018	0.005	0.005	0.01	0.01	1	0.05
11	0.019	0.005	0.005	0.015	0.012	1	0.056	0.016	0.005	0.005	0.015	0.012	1	0.053	0.018	0.005	0.005	0.02	0.012	1	0.055
10	0.019	0.005	0.005	0.013	0.016	1	0.058	0.016	0.005	0.005	0.013	0.016	1	0.055	0.018	0.005	0.005	0.01	0.016	1	0.057
9	0.019	0.005	0.005	0.014	0.018	1	0.061	0.016	0.005	0.005	0.014	0.018	1	0.058	0.018	0.005	0.005	0.01	0.018	1	0.06
8	0.019	0.005	0.005	0.011	0.019	1	0.059	0.016	0.005	0.005	0.011	0.019	1	0.056	0.018	0.005	0.005	0.01	0.019	1	0.058
7	0.019	0.005	0.005	0.01	0.021	1	0.06	0.016	0.005	0.005	0.01	0.021	1	0.057	0.018	0.005	0.005	0.01	0.021	1	0.059
6	0.019	0.005	0.005	0.015	0.024	1	0.068	0.016	0.005	0.005	0.015	0.024	1	0.065	0.018	0.005	0.005	0.02	0.024	1	0.067
5	0.019	0.005	0.005	0.012	0.022	1	0.063	0.016	0.005	0.005	0.012	0.022	1	0.06	0.018	0.005	0.005	0.01	0.022	1	0.062
4	0.019	0.005	0.005	0.014	0.023	1	0.066	0.016	0.005	0.005	0.014	0.023	1	0.063	0.018	0.005	0.005	0.01	0.023	1	0.065
3	0.019	0.005	0.005	0.02	0.006	1	0.055	0.016	0.005	0.005	0.02	0.006	1	0.052	0.018	0.005	0.005	0.02	0.006	1	0.054
2	0.019	0.005	0.005	0.022	0.009	1	0.06	0.016	0.005	0.005	0.022	0.009	1	0.057	0.018	0.005	0.005	0.02	0.009	1	0.059
1	0.019	0.005	0.005	0.015	0.01	1	0.054	0.016	0.005	0.005	0.015	0.01	1	0.051	0.018	0.005	0.005	0.02	0.01	1	0.053

CHANNEL STABILITY ASSESSMENT AND STABILIZATION MEASURE OF MERSA RIVER

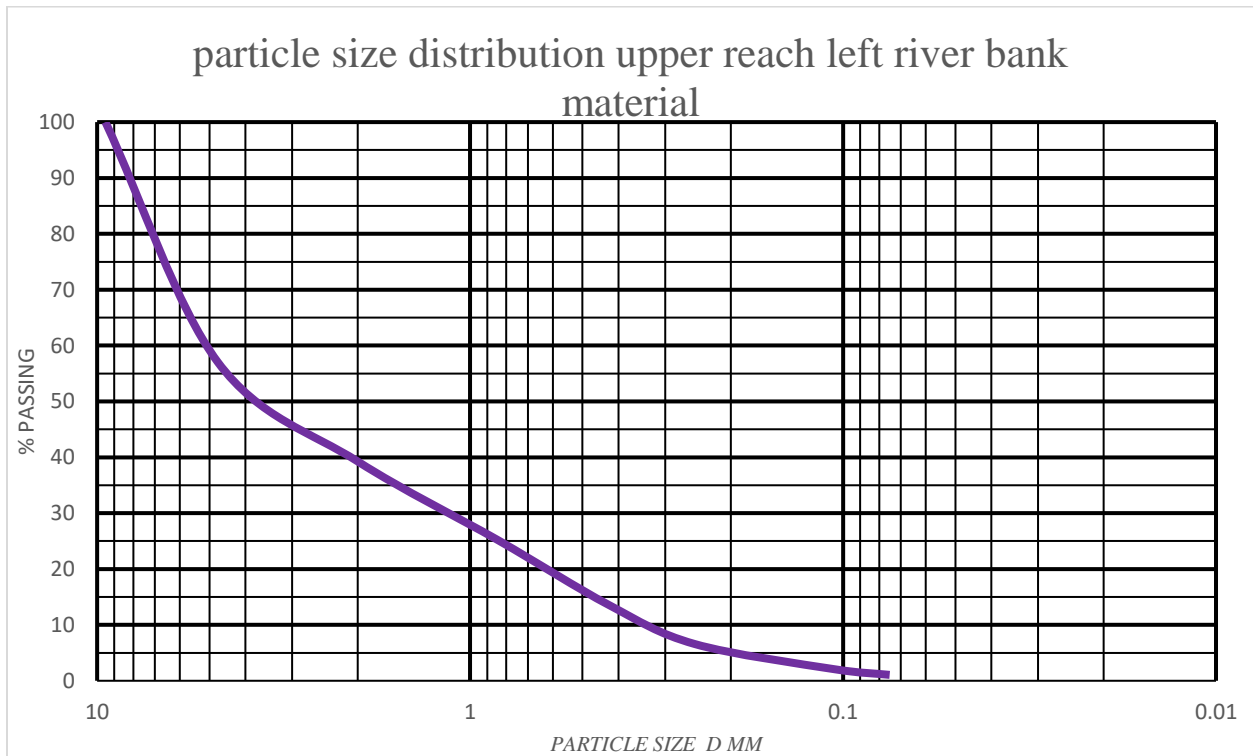
B.3: Downstream reach length in m

Reach	LOB	Channel	ROB
42	64.43	62.47	60.32
41	66.64	70.38	64.65
40	58.83	65.97	66.33
39	69.25	81.29	37.31
38	48.87	40.61	35.42
37	54.97	57.64	72.33
36	71.57	42.65	58.27
35	33.25	56.89	38.11
34	43	52.3	64.46
33	90.21	83.41	62.79
32	65.06	56.72	62.12
31	49.82	82.53	58.02
30	63.87	51.33	76.94
29	32.34	46.46	36.25
28	31.75	49.38	34.47
27	72	45	80
26	75.37	77.78	71.32
25	69.02	82.01	72.8
24	68.08	75.64	76.97
23	72.72	43.72	75.46
22	81	43.02	70.53
21	53.52	52.75	56.17
20	77.87	67.66	49.38
19	55.03	66.8	71.24
18	43.62	63.7	59.71
17	92.3	77.68	70.46
16	82.47	90.39	105.37
15	50.66	65.34	56.94
14	85.12	90.2	85.26
13	57.65	61.92	83.64
12	72.39	73.04	35.28
11	44.2	40.74	77.26
10	84.01	82.2	72.51
9	70.98	74.06	69.07
8	76.95	81.68	84.18
7	76.78	80.3	76.46
6	68.43	33.62	36.27
5	72.73	67.09	67.41
4	54.53	75.97	77.67
3	52.49	38.71	30.94
2	58.37	67.31	61.28
1	0	0	0

APPENDIX C: SAMPLE SOIL SIEVE ANALYSIS RESULT

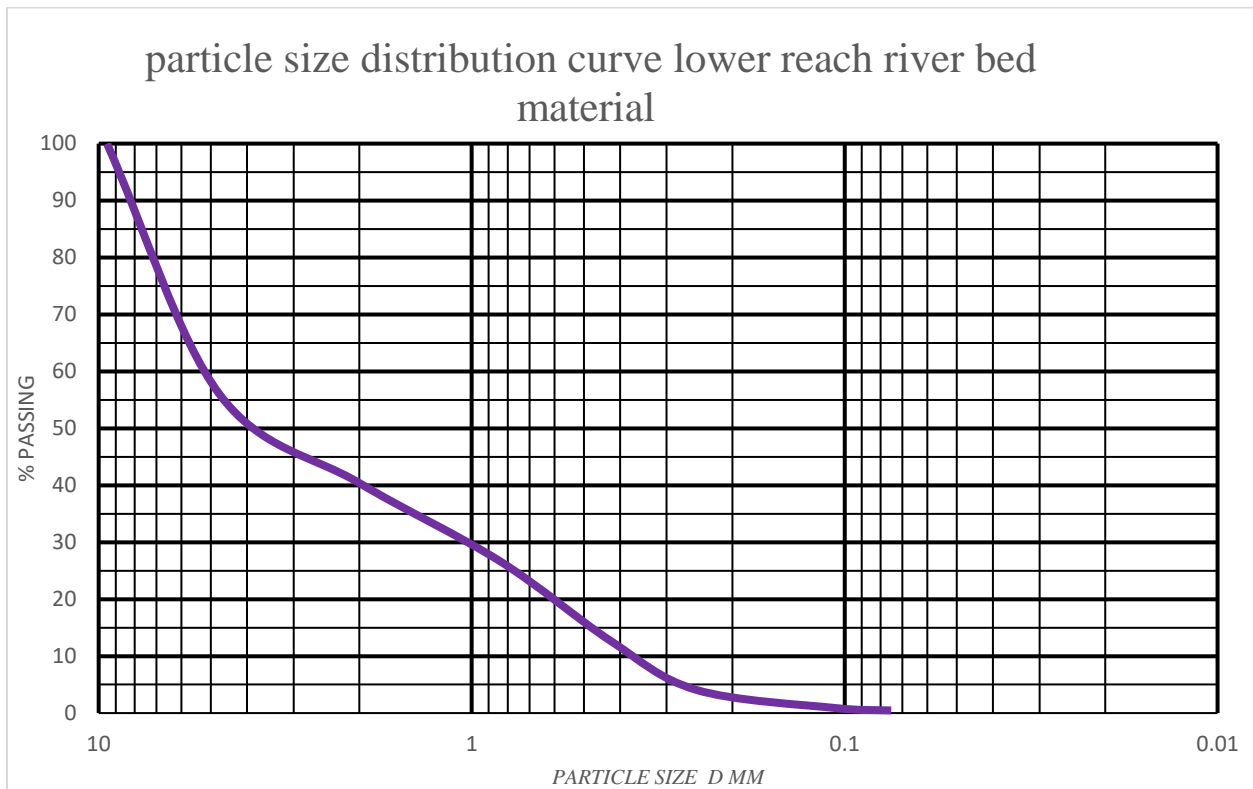
C.1 particle size distribution upper reach left river bank material

sieve No.	sieve diameter (mm)	mass of empty sieve (g)	mass of sieve + Soil retained (g)	soil retained (g)	mass cumulative retained (g)	percent retained (%)
	9.500	495.8	495.8	0.0	0.0	0.00
4	4.750	460.5	696.6	236.1	236.1	42.94
10	2.000	402.6	500.5	97.9	334.0	60.75
20	0.840	386.5	464.1	77.6	411.6	74.86
40	0.425	391.6	455.1	63.5	475.1	86.41
60	0.250	384.1	422.6	38.5	513.6	93.42
140	0.106	363.5	388.2	24.7	538.3	97.91
200	0.075	357.5	363.2	5.7	544.0	98.95
pan		352.6	358.4	5.8	549.8	100.00
total				549.80		



C.2 particle size distribution lower reach river bed material

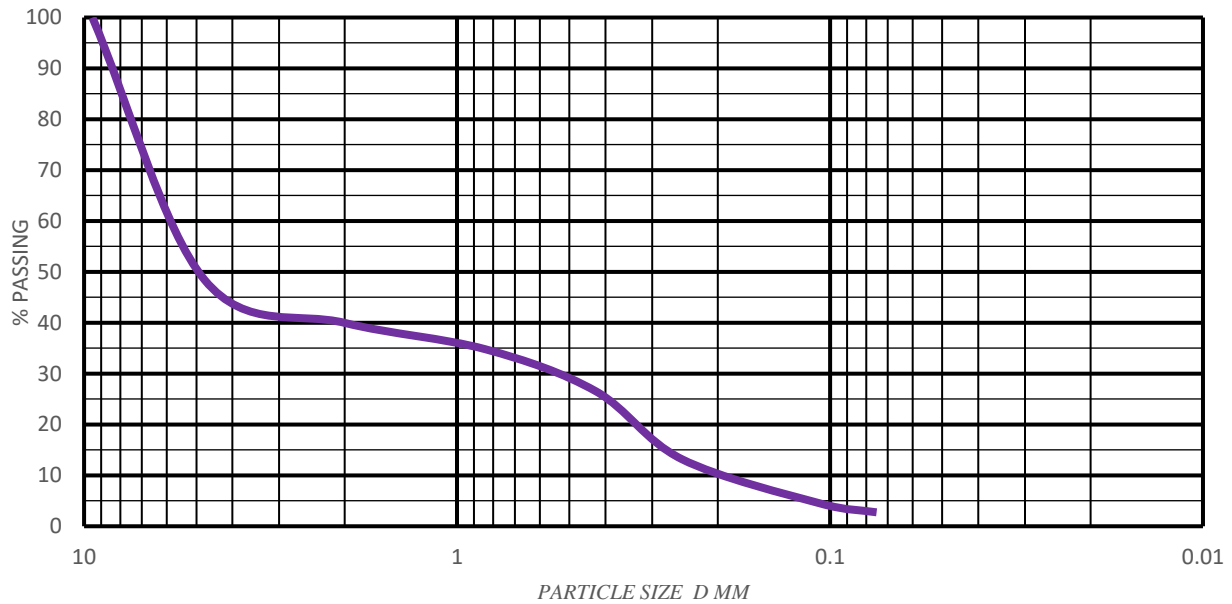
sieve No.	sieve diameter (mm)	mass of empty sieve (g)	mass of sieve + Soil retained (g)	soil retained (g)	mass cumulative retained (g)	percent retained (%)
	9.5	495.8	495.8	0	0	0
4	4.75	460.5	703.2	242.7	242.7	43.99
10	2	402.6	489	86.4	329.1	59.61
20	0.84	386.5	462.2	75.7	404.8	73.32
40	0.425	391.6	468.7	77.1	481.9	87.28
60	0.25	384.1	431.8	47.7	529.6	95.92
140	0.106	363.5	381.1	17.6	547.2	99.11
200	0.075	357.5	359.9	2.4	549.6	99.55
pan		351.6	354.1	2.5	552.1	100
total				552.1		



C.3 particle size distribution lower reach right river bank material

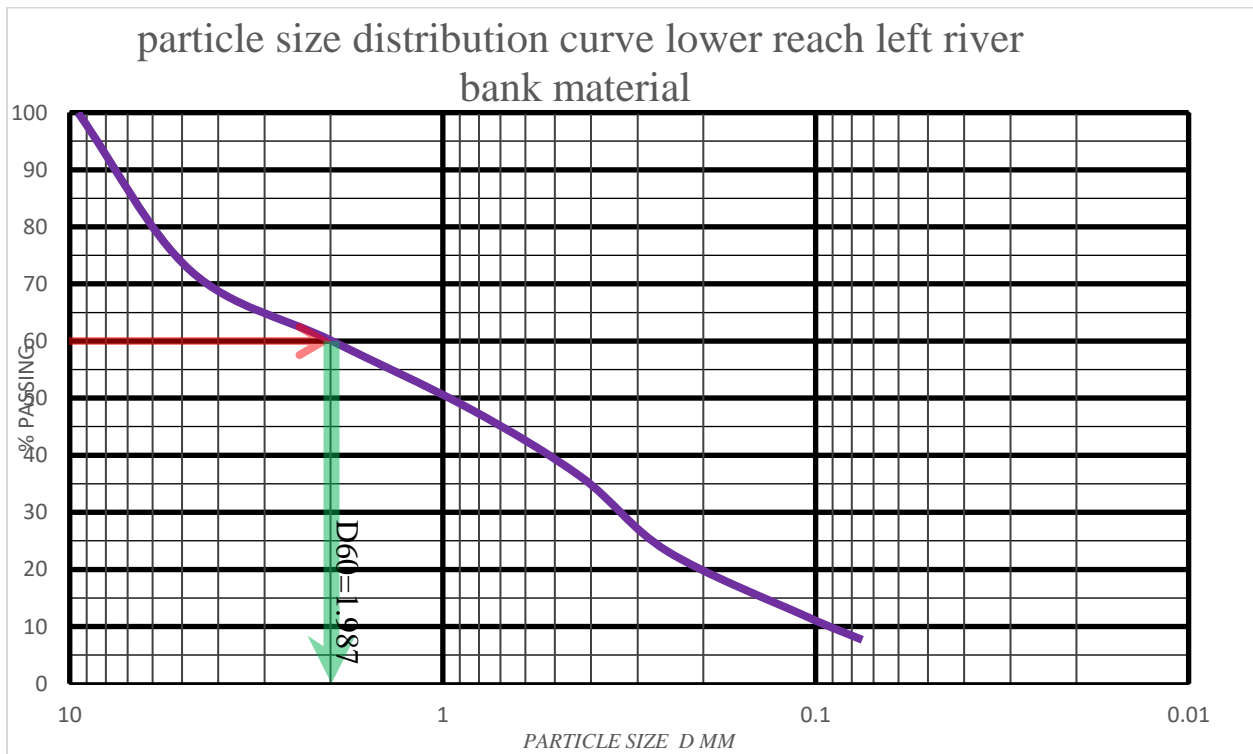
sieve No.	sieve diameter (mm)	mass of empty sieve (g)	mass of sieve + Soil retained (g)	soil retained (g)	mass cumulative retained (g)	percent retained (%)
	9.5	495.8	495.8	0	0	0
4	4.75	460.5	744.7	284.2	284.2	51.59
10	2	402.6	449.1	46.5	330.7	60.03
20	0.84	386.5	415	28.5	359.2	65.20
40	0.425	391.6	437	45.4	404.6	73.44
60	0.25	384.1	457.6	73.5	478.1	86.79
140	0.106	363.5	411.7	48.2	526.3	95.53
200	0.075	357.5	367	9.5	535.8	97.26
pan		351.6	366.7	15.1	550.9	100
total				550.9		

particle size distributon curve lower reach right river bank mataerial



C.4 particle size distribution curve lower reach left river bank material

sieve No.	sieve diameter (mm)	mass of empty sieve (g)	mass of sieve + Soil retained (g)	soil retained (g)	mass cumulative retained (g)	percent retained (%)
2	9.5	495.8	495.8	0	0	0
4	4.75	460.5	613	152.5	152.5	27.65
10	2	402.6	470	67.4	219.9	39.87
20	0.84	386.5	453.3	66.8	286.7	51.98
40	0.425	391.6	457	65.4	352.1	63.83
60	0.25	384.1	455.7	71.6	423.7	76.81
140	0.106	363.5	426.5	63	486.7	88.23
200	0.075	357.5	380.1	22.6	509.3	92.33
pan		349	391.3	42.3	551.6	100
total				551.6		



APPENDIX D: HEC-RAS SEDIMENT OUTPUT

Sediment entry (mass cumulative in) tones

RS	station (m)	year						
		2006	2007	2008	2009	2010	2011	2012
42	0	16108.18	19195.68	21764.17	23347.83	24479.67	25857.77	27267.7
41	67.31	15997.85	19262.4	22004.15	23633.14	24769.18	26150.4	27573.45
40	106.02	16682.77	20280.41	23206.96	24988.34	26138.29	27578.78	29031.14
39	181.99	17787.39	21655.39	24865.84	26671.7	27824.95	29311.67	30787.38
38	249.08	19221.88	23685.24	27197.91	29140.84	30311.32	31813.03	33326.51
37	282.7	21106.64	25916.56	29768.91	31749.32	32921.01	34423.43	35951.93
36	363	21321.45	25932.48	29891.86	31712.43	32884.11	34386.52	35924.06
35	444.68	22479.59	27634.64	32051.49	33923.41	35095.85	36598.48	38157.23
34	518.74	26800.92	31731.09	34007.58	35723.62	36901.79	38406.97	40016.06
33	600.94	26433.36	31793.2	34074.51	35790.55	36968.72	38473.91	40096.69
32	641.68	27110.74	32447.54	34728.94	36444.98	37623.16	39128.34	40624.79
31	714.72	29691.38	35533.24	37820.27	39536.31	40714.49	42219.7	43739.43
30	776.64	31419.52	36239.42	37311.42	38547.74	39531.25	40856.85	43091.66
29	866.84	26686.18	31788.13	32860.13	34096.45	35079.96	36405.56	38640.36
28	932.18	22009.4	27015.32	28095.01	29349.85	30345.83	31688.05	33932.9
27	1022.57	20478.06	25657.65	26737.33	27992.76	28988.75	30330.97	32577.27
26	1100.25	22655.09	24163.47	25243.16	26527.01	27529.08	28871.39	31189.9
25	1163.95	21941.54	23451.99	24531.68	25815.66	26817.73	28160.03	30478.57
24	1230.75	19929.42	21485.09	22673.71	23989.21	25053.56	26450.11	28826.87
23	1298.41	17599.23	19154.9	20343.52	21659.02	22723.37	24119.92	26491.42
22	1351.16	17880.24	19436.92	20625.54	21941.14	23005.54	24402.13	26778.34
21	1394.18	17207.98	18805.56	20005.14	21336.17	22406.82	23803.81	26188.71
20	1437.9	16744.5	18342.07	19541.65	20872.69	21943.34	23340.33	25725.22
19	1513.54	16251.12	18178.32	19597.65	21148.74	22317.8	23786.34	26537.67
18	1595.55	14773.4	16698.33	18190.32	19667.8	20859.77	22346.51	24964.01
17	1673.33	17499.49	19456.62	20827.98	22509.66	23711.66	25333.66	26336.01
16	1718.33	19922.27	23825.16	29139.46	31915.58	33279.09	34775.93	35712.99
15	1767.71	28416.75	34267.32	36930.79	39289.26	40615.07	42151.85	43094.53
14	1814.17	33092.45	39792.68	41353.56	42779.06	43496.48	44504.19	45445.38
13	1865.5	33183.4	36520.54	36822.07	36822.07	36822.07	36822.07	36822.07
12	1948.03	28165.29	29130.64	29432.16	29432.16	29432.16	29432.16	29432.16
11	2004.75	22140.27	23105.67	23407.2	23407.2	23407.2	23407.2	23407.2

CHANNEL STABILITY ASSESSMENT AND STABILIZATION MEASURE OF MERSA RIVER

10	2088.16	12579.63	13545.06	13846.58	13846.58	13846.58	13846.58	13846.58
9	2140.46	7927.186	8892.637	9194.162	9194.162	9194.162	9194.162	9194.162
8	2197.35	6987.535	7954.179	8257.17	8257.17	8257.17	8257.17	8257.17
7	2240	6227.16	7197.196	7500.187	7500.187	7500.187	7500.187	7500.187
6	2297.64	5465.185	6439.806	6742.95	6742.95	6742.95	6742.95	6742.95
5	2338.25	4634.372	5575.395	5878.539	5878.539	5878.539	5878.539	5878.539
4	2419.54	4316.624	5302.669	5617.929	5617.929	5617.929	5617.929	5617.929
3	2485.51	2849.317	2849.317	2849.317	2849.317	2849.317	2849.317	2849.317
2	2555.89	973.664	973.664	973.664	973.664	973.664	973.664	973.664
1	2618.36	0	0	0	0	0	0	0

Sediment leave (mass cumulative out) tones

RS	station (m)	year						
		2006	2007	2008	2009	2010	2011	2012
42	0	16273.16	19180.78	21614.65	23166.35	24298.20	25674.57	27083.13
41	67.31	16108.18	19195.68	21764.17	23347.83	24479.67	25857.77	27267.70
40	106.02	15997.85	19262.40	22004.15	23633.14	24769.18	26150.40	27573.45
39	181.99	16682.77	20280.41	23206.96	24988.34	26138.29	27578.78	29031.14
38	249.08	17787.39	21655.39	24865.84	26671.70	27824.95	29311.67	30787.38
37	282.7	19221.88	23685.24	27197.91	29140.84	30311.32	31813.03	33326.51
36	363	21106.64	25916.56	29768.91	31749.32	32921.01	34423.43	35951.93
35	444.68	21321.45	25932.48	29891.86	31712.43	32884.11	34386.52	35924.06
34	518.74	22479.59	27634.64	32051.49	33923.41	35095.85	36598.48	38157.23
33	600.94	26800.92	31731.09	34007.58	35723.62	36901.79	38406.97	40016.06
32	641.68	26433.36	31793.20	34074.51	35790.55	36968.72	38473.91	40096.69
31	714.72	27110.74	32447.54	34728.94	36444.98	37623.16	39128.34	40624.79
30	776.64	29691.38	35533.24	37820.27	39536.31	40714.49	42219.70	43739.43
29	866.84	31419.52	36239.42	37311.42	38547.74	39531.25	40856.85	43091.66
28	932.18	26686.18	31788.13	32860.13	34096.45	35079.96	36405.56	38640.36
27	1022.57	22009.40	27015.32	28095.01	29349.85	30345.83	31688.05	33932.90
26	1100.25	20478.06	25657.65	26737.33	27992.76	28988.75	30330.97	32577.27
25	1163.95	22655.09	24163.47	25243.16	26527.01	27529.08	28871.39	31189.90
24	1230.75	21941.54	23451.99	24531.68	25815.66	26817.73	28160.03	30478.57
23	1298.41	19929.42	21485.09	22673.71	23989.21	25053.56	26450.11	28826.87
22	1351.16	17599.23	19154.90	20343.52	21659.02	22723.37	24119.92	26491.42
21	1394.18	17880.24	19436.92	20625.54	21941.14	23005.54	24402.13	26778.34

CHANNEL STABILITY ASSESSMENT AND STABILIZATION MEASURE OF MERSA RIVER

20	1437.9	17207.98	18805.56	20005.14	21336.17	22406.82	23803.81	26188.71
19	1513.54	16744.50	18342.07	19541.65	20872.69	21943.34	23340.33	25725.22
18	1595.55	16251.12	18178.32	19597.65	21148.74	22317.80	23786.34	26537.67
17	1673.33	14773.40	16698.33	18190.32	19667.80	20859.77	22346.51	24964.01
16	1718.33	17499.49	19456.62	20827.98	22509.66	23711.66	25333.66	26336.01
15	1767.71	19922.27	23825.16	29139.46	31915.52	33279.09	34775.93	35712.99
14	1814.17	28416.75	34267.32	36930.79	39289.26	40615.07	42151.85	43094.53
13	1865.5	33092.45	39792.68	41353.56	42779.06	43496.48	44504.19	45445.38
12	1948.03	33183.40	36520.54	36822.07	36822.07	36822.07	36822.07	36822.07
11	2004.75	28165.29	29130.64	29432.16	29432.16	29432.16	29432.16	29432.16
10	2088.16	22140.27	23105.67	23407.20	23407.20	23407.20	23407.20	23407.20
9	2140.46	12579.63	13545.06	13846.58	13846.58	13846.58	13846.58	13846.58
8	2197.35	7927.19	8892.64	9194.16	9194.16	9194.16	9194.16	9194.16
7	2240	6987.54	7954.18	8257.17	8257.17	8257.17	8257.17	8257.17
6	2297.64	6227.16	7197.20	7500.19	7500.19	7500.19	7500.19	7500.19
5	2338.25	5465.19	6439.81	6742.95	6742.95	6742.95	6742.95	6742.95
4	2419.54	4634.37	5575.40	5878.54	5878.54	5878.54	5878.54	5878.54
3	2485.51	4316.62	5302.67	5617.93	5617.93	5617.93	5617.93	5617.93
2	2555.89	2849.32	2849.32	2849.32	2849.32	2849.32	2849.32	2849.32
1	2618.36	973.66	973.66	973.66	973.66	973.66	973.66	973.66

Profile plot sediment leave at 2012

