

Zambezi River - sea route for the SADC Region: A study on how to extend navigation on the Zambezi River

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Abstract

The study investigated the possibility of expanding commercial navigation by fact and by statute on the Zambezi River. The Zambezi is navigable from the sea to Cabora Bassa. Continuous navigation is not possible beyond Cabora Bassa to Kariba; and beyond Kariba to Victoria Falls due to existence of geomorphic obstructions and poor accountability, regulation and control of the use of surplus basin water balance. This research defined technological means of overcoming these physical obstacles and explained how the water levels necessary for improving its navigability rating can be maintained throughout the year by implementation of a water resource management strategy which ensures effective regulation and control of the surplus basin water which is currently the cause of downstream flooding. The focus was on tracing the route followed by the river from Kazungula to the sea byway of satellite images and counting the different types of obstructive geomorphic features and manmade impoundments along it in order to establish whether methods of civil engineering and marine technology could not be used to improve the channel platform of the river. The study recognized the theoretical framework for the determination of basin water balance that is hereby stated as:- the difference between the sum of long term mean annual rainfall, local run off, ground water and inflow minus evapotranspiration, groundwater, coastal and Zambezi outflows. Satellite pictures were used in presenting geomorphic features and manmade impoundments and the method of geographical interpretation of aerial photographs was used in the analysis. The major findings and recommendation of the study was a call for the development of additional hydro infrastructure to facilitate commercial navigation and development of an effective water management strategy that balances technological issues with the requirements of environmental sustainability by a process of dialogue amongst all the major parties involved i.e. the private sector, civil society, governments, affected communities, scientists and international financial institutions.

Key Words: Channels, platforms, dykes, gates, groynes, locks, jetties

1. INTRODUCTION

The World Commission on Dams (WCD) knowledge base describes the development of large dams with locks, gate levies and other water impounding structures on major rivers such as the Zambezi, as the cause of impacts on the ecosystem which affects biodiversity, causes emission of greenhouse gases, alters downstream flow, disturbs downstream fisheries and affects natural food cycle. The report

estimates that; dams, inter basin transfer and water withdrawals have fragmented 60% of the Worlds Rivers. The development of the Zambezi water as an inland waterway is an attempt to promote development within its basin by balancing civil engineering issues with the requirements of environmental sustainability.

This paper focuses on the identification and improvements of the non- navigable sections of the Zambezi River and on how the resultant

expansion of navigation will impact on the flood control.

1.1. Background Information

The World Commission on Dams WCD report, *Dams and development: A new Framework for Decision-making* published in 2000 was accompanied by hopes that broad-based agreements would be forged on how to better manage water and energy development. The report grew out of the controversy over the economic, social and environmental consequences of large dams built in the 20th century. The WCD was established in February 1998 through a process of dialogue amongst all the major parties engaged in conflicts over dams, the private sector, civil society, government, affected communities, scientists and international financial institutions.

This Framework for Decision Making is the one that for the past decade has been influencing decision making on the construction or development of waterways especially the impoundment of large rivers into dams for flood control and hydro electricity generation. Some aspect of past conflict stemmed from the lack of agreement on basic factual issues related to the consequences-good or bad- of large dams. Whenever one stakeholder group issued a report or research or evaluation, other stakeholders would perceive that the information presented was biased. The WCD report presented three Global norms, five Core Values, five key Decision points, Seven Strategic Priorities, 33 associated Policy principles and 26 Guidelines. The task of trying to determine how

best to combine these recommendations into operational practices in particular by developing countries was observed to be a great challenge for post WCD activity, such as the expansion of navigation on the Zambezi river by the construction of large scale water impounding structures by SADC.

This study was brought about as a result of the shift in thinking which occurred ten years later in 2010, when a group of scientists published a special issue referred to as “Water- Alternatives” which revisited the WCD restrictions of inland water development. Water alternatives re-examines the influence and the impacts of the WCD for the past decade on policies and practices of key stakeholders and institutions; development outcomes for affected communities and environments. In particular calls for the exploration the new drivers of dam development that have emerged during the last decade, including climate change, new financiers of dams and diverse perceptions. The context of this study is that human demand for water energy and cheap transport for raw materials continues to grow in the SADC region and that the development of the Zambezi River remains the solution of choice for regional governments, private companies and financial investors.

Despite the legacies and controversy of the two large dams on the Zambezi which continues to cause conflict between providing hydropower, water supply, flood control, irrigation and other substantial benefits to many whilst devastating the basic rights and livelihood of others, and damaging shared rivers and eco systems the

Kariba and Cabora Bassa Dams have made an important and significant contribution to human development and the benefits derived from them have been considerable.

Water transport is considerably more efficient in energy use than is rail; rail is more efficient than road; and road is more efficient than air. By utilizing the cheap and abundant power of the Zambezi we can raise the standard of living of SADC countries and can help preserve the thousands of acres of woodlands in the Zambezi basin and stop the poor rural person without cheap electricity from chopping down such woodlands. To improve development outcomes in the future, we need to look at proposed water and energy projects in a much wider setting that reflects full knowledge and understanding of the benefits and impacts of large dam projects and alternative options for all parties.

Communities can live for decades starved of development because a project is not receiving serious consideration by those reluctant to invest in areas prone to flooding or yielding to resistance from environmental pressure groups.

1.2. Rational

It has been confirmed that in most developing countries public transport has been characterized by inefficiency, poor maintenance, and unaffordability especially to the poor who constitute the majority.

Traffic congestion has been described as the situation that arises when road and networks are no longer capable of accommodating the volume of movement that occurs on them.

Various section of the Zambezi River have been used for navigation in the past yet the low economic growth of the SADC region in the last two decades has been attributed to the very little development of new navigation in the Zambezi Basin.

In the SADC region water resource management among member states is governed by the Revised Protocol on Shared Watercourses. A technical unit under the SADC Secretariat is responsible for water resource management in the region. Trans-boundary river basin management of the Zambezi River is one of those areas in which the division has been very active for a long time and one of its highlights has been the signing and ratification by the SADC Countries of the Protocol on Shared Water Course Systems first adopted in 1995 and revised in 2001. This study has brought out the following facts:-

- (i) Existing flood prone areas are located in areas in the lower Zambezi where there is very little river regulation.
- (ii) That existing hydraulic infrastructure development in the form of large dams although it has impacted in terms of river regulation and change of hydrological characteristics it does not contribute significantly to flood regulation especially in case of floods caused by large scale atmospheric events such as cyclone spanning across extensive areas of the basin.
- (iii) It has also brought out the fact that construction of more water impounding structures and improved reservoir operations for

the two man-made reservoirs in the basin will have considerable benefits for both ecology, flood mitigation and socio economic development in the region and,

(iv) That from a civil engineering point of view anything is possible –if cost is not a factor.

1.3. Problem Found In the Zambezi Basin

Every year in the past decade people living in the Lower Zambezi, Tete, Shire confluence all the way to the Zambezi Delta have been subjected to perennial flood disasters that have cost many lives, destroyed property worth millions of dollars and contributed to the disruption of livelihoods and economic activities. The floods affect people's livelihood, food security and socio-economic activities thus making communities in the basin vulnerable and in need of food, shelter, water and sanitation.

Mitchell (1981) confirmed that there are two purposes for a dam, first it regulates flow of the lower river and it creates a navigable lake above the dam. It has also been confirmed by Trethowan (1981) that in the original planning of the Cabora Bassa, it was envisaged that the Zambezi below the dam wall would be developed to afford safe navigation. Mitchell noted that flow regulation by Cabora Bassa was not sufficient to render the lower Zambezi navigable. Dr. Livingstone in his voyage of 1858-1863 came to the conclusion that if the river was in flood and therefore 25 metres high it would be navigable.

Since then no additional water impoundment structures have been constructed nor has there

been physical mitigation measures to control flooding. Movement of the bulk of goods and raw material is still transported by overland means causing port congestion in most of the riparian states.

1.4. Main Objectives

The overall aim of this study was to identify areas between Kazungula and Indian Ocean that need channel improvement in order to facilitate constant depth of flow, uninterrupted navigation and improved downstream flood control measures. The study focused on the following: basin physiography and morphology, land cover use within an areas +50 kilometers on side of the river channel, sub basin characteristics, run off and basin water balance, flow regimes and regulation and on recommendable designs. To achieve this end it is best that one assumes the following:- that the resource base of the region is good enough for financing projects of such magnitude, that the earth satellite photos show all the attributes that are involved in the physiography and morphology of the river channel and of ground water, that the Zambezi River Authority and SADC Secretariat and existing independent data bases have up to date information on flow regimes, run off and basin water balance and that regional governments will cooperate with each other in reducing regional conflicts and interstate riparian disputes that may slow development in the basin at large.

2. METHODOLOGY

The Method of Intra-Regional Analysis, stream bank reconnaissance techniques, map interpretation, document analysis, field visits, and geographic interpretation of satellite photographs, observations and interview were found as most appropriate techniques for such a study.

All the data obtained from documents and photo interpretation from satellite information was analyzed through deductive means.

2.1. Limitations

The length and breadth of the river made it impossible to conduct comprehensive field work without the use of secondary data.

It should be realized that the Zambezi is one of the most written about rivers in the world and this study attempts to put all pieces together to come up with a coherent result.

3. RESULTS

Current Bibliography of Zambezi basin physiography and morphology contains material on the hydrology and flow records of the major river published between 1960 and 2010. The bibliography lists books, articles, abstracts, maps, Ph.D. and M.Sc. theses and reports. Special emphasis should be given to local material which does not reach international bibliographies or databases. Most of the material in the bibliography is available at the Harare Archival Centre, Harare, and the Zambezi River Authority Library at Kariba Heights, Kariba and Zimbabwe National Water Authority Head Office in Harare.

The materials describe the Zambezi Rivers basin characteristics and flow regime. There are many problems on hydrology and climate change that currently prevent the Zambezi from becoming a smooth flowing and perennially navigable river. These problems include cyclic hydrological changes in the Zambezi River Basin, effects of existing hydro power generation, demand side management and ecological concerns. The Zambezi Hydrology is the most important determinant of wetland functions and value worldwide. In large basins such as that of the Zambezi the composition, structure and function of the hydrological system from basic biological processes of primary production, decomposition and consumption to complex reproductive adaptation of plants and animals all depend on the hydrological connection between river and flood plains. It can further be argued that there is a connection in terms of lateral exchange of nutrients and sediment between a river and its flood plain. With reference to occurrence of floods in the basin one would not be far from truth to say that flood events have uncertain characteristics which depended on regional climatic conditions and other factors such as the magnitude, timing, duration and frequency of hydrological conditions which fall within a predictable range and pattern over time.

Available literature shows that the Zambezi River system has undergone profound social and ecological changes over the past century but for which limited pre-impact studies are available. Although the World Commission on Dams (2000) confirms that the predictability of

hydrological regimes of rivers maintains the flood plain agriculture systems, fisheries, pastures and forests that constitute the organizing element of community livelihood and culture this fact alone should not be taken to be impediment to other sustainable developments that need to be implemented on the river.

Efforts to ameliorate adverse hydrological changes in the flooding regime by further development of hydro infrastructure on the Zambezi must begin with an understanding of how hydrological processes have diverged with time from their historically unpredictable character to their predictable state of today. Navigation potential can be fully exploited when a balance between predictability of hydrological regime and technological advances is struck.

The geomorphologic features that influence navigation on inland rivers vary in nature and include prevalence of physical obstructions such as gorges, steep and shallow grades, narrow passages, sand banks, shifting sands, shifting banks, whirlpools, anabranch and rapids. Also navigation is affected by the gradient of flood plains in low lying areas which causes flood inundation of extensive areas as the river approaches the sea not to mention delta conditions, river load deposition and changes in tide levels.

The development of the Zambezi River as an inland waterway is an attempt to promote development within its basin by balancing the pattern of its geomorphic channel platform using modern technologies of civil engineering with the requirements of environmental sustainability in

order to facilitate smooth sailing of commercial traffic.

There are arguments that when flooding regime is disrupted due to dams, embankments or diversion the hydrological connection between river and flood plain is altered or severed. A fact which is further emphasized by numerous studies from different parts of the globe that have documented the adverse effects of reduced and regularized flood flows worldwide to include:- (i) reduced silt deposition, (ii) reduced nutrient availability, (iii) channel degradation, (iv) loss of shallow wetlands and open areas, (v) altered food chain dynamics, (vi) reduced heterogeneity and fragmentation, (vii) intrusion of salt water, (viii) displacement of wetland vegetation by upland species, (viii) disrupted reproductive patterns for fish and wild life species and (ix) loss of coastal mangroves.

Assessments of the satellite photographic pictures and physical evidence on the ground gave a clearer picture of the present state of river channel through which navigating vessels would have to go through to achieve smooth sail.

Mitchell (1981) professes in a simple way that channels could be dredged to give a depth and width which is sufficient for barges to go through particularly in the low lying areas.

In order to create a channel that is navigable throughout the year there must be sufficient supply of water, wide enough passage, and sufficient depth of water, minimal obstruction, constant flow rate and nondestructive velocities.

The theoretical principle underlying the full exploitation of the navigability of the Zambezi River lies in the management and use to which its basin water balance is put throughout the year.

4. DISCUSSION

It is acknowledged that basin water balance is an essential tool for understanding the hydrological regime of the Zambezi basin and essential for assessing the impact of development activities such as navigation and flood mitigation. In other words the criteria for judging the navigability potential of Zambezi River should be based on the ability of existing hydrologic infrastructure to conserve basin water balance throughout the year. This should be achievable by the development of an efficient flood regulation system.

In its simplest terms basin water balance is the difference between mean run off and net run off derived from secondary data after all other uses had been provided for. A more realistic and all-encompassing method is that by Beilfuss and Dos Santos (2001).

This Method expresses basin water balance which causes flooding in the flood prone areas as made up of the following:-

$$\Delta S = [S_{t+1} - S_t] \dots \dots \dots (1)$$

$$\Delta S = [P_t + R_t + G_t + Q_t - ET_t - g_t - q_t - D_t] \dots (2)$$

Where S = volume of water stored in the basin or flood plain

$$\Delta S = \text{Basin Water Balance}$$

P = Rainfall

R = Run off from surrounding catchments

G = Ground water inflow

Q = Surface water in flow from the Zambezi River

ET = Evapotranspiration

g = ground water outflow

q = surface water outflow to the Zambezi river

D = surface drainage to the coast at time t

t = time

The central tendency and variation of input of water stored in the surface and subsurface define the basin water balance. If the regional climatic conditions are stationery (no long term shifts in mean conditions) and rainfall run off characteristics in the catchment remain unchanged over a long period of time there is no net change in water storage in the flood plain and the annual water balance can be re-stated as

$$\Delta S = [P + R + G + Q - ET + g + D + q] \dots \dots (3)$$

Or simply stated - the sum of long term mean annual rainfall, local run off, ground water and Zambezi River inflow is balanced by evapotranspiration, groundwater, coastal and Zambezi outflows.

The last equation sums up the pre-requisite condition for maintaining a navigable river system.

4.1. Archimedes Law on Floatation

For marine vessel to be able ply up and down the Zambezi River or its lakes the two most common types of hydraulic flow referred to as uniform and non-uniform flow, Bernoulli's principle on energy gradients for flow in open channels, and Archimedes principle on floatation must apply. In uniform flow in channels it is assumed that successive cross-sections and corresponding mean velocities were everywhere the same and that the loss of head in friction was equal to the fall of the channel bed so that bed, water surface and energy gradients were parallel. However this principle is inapplicable to flow in the Zambezi River. Instead the principle on non-uniform flow applies throughout in which depth varies from section to section and the energy gradient, water surface and bed needed not necessarily be parallel. Loss of head is estimated by the fall in the energy gradients and not by the fall in the water surface or bed level. Critical velocities and critical depth are considered to be subject to influence from other external factors but their importance should be emphasized for those areas that needed bank strengthening or protective flood barriers.

Studies carried out by the Zambezi River Authority / SADC show that a water depth of 3metres would be sufficient for floatation of the simplest commercial vessel. It is an accepted fact that a floating body always displaces its own weight of the fluid that supports it. A body floating on the free surface is in stable equilibrium for small vertical displacements, thus if it is further depressed, more liquid is displaced and the up-thrust, now greater than the weight restores it to the original position. For small

horizontal displacement it is stable if the up-thrust through the centre of gravity (the centre of buoyancy) gives with the weight a restoring couple. For a ship this is expressed by saying that the point called the metacentre, at which the vertical line through the center of buoyancy intersects the plane of symmetry of the vessel, must always be above its centre of gravity to achieve stability.

Satellite photographs were used in the location of obstacles such as shifting sands, shifting banks, rapids and small islands which reduce depth of water necessary to allow floating vessels to move. The located areas were labeled and marked on the respective photographs.

4.2. Navigational Uses of the Zambezi River

The Zambezi River Authority (2007) acknowledges that various sections of this river have been used for navigation in the past but there has been little development of new navigation in the last three decades as is evidenced by the relatively low economic growth within the river basin. Navigable waterways are classified into three i.e. (i) natural channels, (ii) canalized rivers and (iii) general canals. The natural channels are those portions of the Zambezi River, including estuaries, the normal flow of which would not be interfered with by artificial works. The canalized sections would be those the flow of which would be more or less under artificial control and last but not least canals would be those section were they are entirely artificial or where manmade canal

would be constructed as bypass to sharp curves or obstacles in the normal course of the river.

The distinction between the three is found to be fundamental. In the case of the natural channel, improvement works would be limited to a rectification of the bed and no attempt would be made to control or augment the natural flow of water; which being derived from the basin is normally sufficient for navigation within the limits of the channel. The canalized sections of the river would be those portions of the river consisting of sections in which the natural flow is conserved and controlled, as is the manner of a canal but generally without extraneous sources of water supply. Canals being works of an entirely artificial character would have to be fed with supplies obtained by the interception of streams or from other external sources, frequently necessitating pumping and reservoir storage such as balance dams.

4.3. Impediments to Navigation

The initiatives require improved berthing infrastructure, flow level regulation, aquatic weed control in selected places and dredging. In the seaward section the most pronounced disability is shifting sand bars at river exit. The study found out that for the removal of sand bars the most efficient means, producing immediate results would be dredging but that the effect in the majority of the cases would be temporary and would require continuous operations. Satellite photos show that bars are not very pronounced and that the river mouth is encumbered by shoals, due to either detritus brought down by the river itself or due to coastal

erosion and drift. Coming further along the uppermost entrance to the sea upstream dredging may need to be resorted to for a permanent benefit by training works of a scope and magnitude dependent on circumstance.

Such work would include longitudinal training walls or embankments and groynes, dykes or jetties. Evidence from studies by Mitchell (1981), Trethowan (1981) Zimbabwe Water Authority (ZWA) (2000), and Zimbabwe National Water Authority (ZINWA) (1980) goes to show several sites that have been identified as suitable for the development of hydro infrastructure. The sites were identified from satellite photographs as Batoka Gorge, Devils Gorge, Mpata Gorge, Mpanda Uncua, Boroma, Lupata, Mutarara and Chinde.

4.4. Pattern of Run Off In The Zambezi Basin

Rainfall throughout the Zambezi catchment is concentrated over a 4-6 month rainy season in response to the movement of the Inter-tropical Convergence Zone. This annual cycle of rain was said to give rise to the unique patterns of run-off in each sub basin. Rivers draining the steep gorges of the Central Africa plateau peak rapidly with the rain, reaching their maximum discharge between January and March and decreasing to minimal dry season flows by October- November. In the Zambezi headwaters Kafue River and Shire basin large flood plain system captures flood water and may delay discharge until late in the rainy season or early dry season.

The construction of Kariba, Cabora Bassa and other large Dams in the Zambezi system has profoundly altered Zambezi run-off pattern.

Kariba Reservoir is for regulating run off from Zambezi headwaters region of the Upper Zambezi Catchment and the Western portion of the Middle Zambezi catchment between Victoria Falls and Kariba . Regulation by the Kariba results in altering: - (i) the timing, (ii) magnitude, (iii) duration and (iv) frequency of flooding events. The Cabora Bassa Reservoir similarly regulates run off from the remaining Middle Zambezi catchment between the Kariba and Cabora Bassa Gorges, including regulation of flows from the Kafue River and unregulated flows from the Luangwa River as well as outflow from Kariba.

Only run off from tributaries of the Moravia-Angonia and Manica Plateaus in the Lower Zambezi are said to be unaffected by river regulation.

The effects of flood regulation on navigation in a river system were first mentioned by Dr. David Livingstone during his Zambezi expedition of 1858 to 1863 and in more recent times river regulation methods have been applied by developers of the Morris Canal Technology of USA; Suez Canal and Panama Canal Engineers.

Estimates of historical mean annual runoff for each of the sub basins are made using measured daily flows provided by the country teams and captured in independent data bases and published records. This data can be

supplemented by flow data from the ZAMWIS database. A total value of the basin run off was determined in order to determine basin water balance that could be used in determining navigable river levels.

4.5. Floods

Flooding in the Zambezi river system is as a result of excess unregulated basin water balance. The floods known to occur between Kariba and the sea can be characterized into two main types: Type I - floods due to over bank flows upstream of Cabora Bassa Reservoir and Lower Tete and Type II- floods in swamps, wetlands and flat areas along the extensive Lower Zambezi Delta; the main difference between the two types being the recurrence and extent of flooding. While Type I floods occur almost every rainy season to some extent Type II is usually associated with extreme rain conditions in the basin.

The existing flood prone zones are located in areas with little river regulation mainly along the area subjected to run off from tributaries of the Moravia-Angonia and Manica Plateaus in the Lower Zambezi. The presence of Kariba Dam and Cabora Bassa Dam although it has impact in terms of (i) river regulation and (ii) change of hydrological flow characteristics; it does not contribute significantly to flood regulation especially in case of floods caused by large-scale atmospheric events such as cyclones spanning across extensive areas of the basin.

More work in the development of hydraulic infrastructure along the river course needs to be

done in order to achieve this objective. This view was shared by Mitchell (1981) on proposing that effective control of flooding in the Lower Basin would best be managed by the construction of additional infrastructure such as levies, locks and gates at Mpanda Uncua, Boroma, Lupata and Mutarara.

Long term changes in delta flooding pattern were already known when Mitchell (1981) proposed the idea of locks and that the delta flooding regime resulted from the complex interaction of regional run off patterns with local geomorphology, rainfall run off and tidal fluctuations at the coast.

In any case the primary objective of developing effective flood regulation infrastructure is to create manageable navigable channels that do not spill over banks at full supply or high flood levels.

4.6. Flow Regimes and Regulation

The longest flow records available for the Zambezi river have been measured just upstream of the Victoria Falls at three different sites:- Railway Station North Bank (1907-1924), the Livingstone Pump house Station North Bank (1924-1973) and the Victoria Falls Big Tree Station South Bank (1973-present) all of which are now referred to as the Victoria Falls Flows. Flow records show that the velocity of the river varies very considerably and that some sections of the river require floats, others current meters or pressure tube (pitot tubes) to determine positions of maximum velocity.

Floods and droughts are part of the hydrological features of the Zambezi River basin and occur cyclically. The majority of the population in the nearby rural areas practice subsistence agriculture along the flood plains, swamps, wetlands and margins of large water bodies. Although for the larger parts of the river basin the threats related to flooding are found to be limited, the situation is different in some sections of the upper, middle and lower Zambezi where historical records showed that floods inundate extensive areas and result in serious infrastructure damage and effects to people and property.

4.7. Protection of River Banks

The geology in the basin is mostly of hard impermeable crystalline basement metamorphic and igneous rocks with mostly inundated Paleozoic sediments and these lithologies are predominantly in the areas downstream of and to the eastern of Livingstone. Further evidence cited from written literature indicates that the geology of the Zambezi basin as a whole is confounded by lack of harmonization of geological descriptions. There is no standardization of forms divisions and structures adopted in different riparian countries available. Generally it is observed that banks of soft erodible character may be artificially protected, where stone is procurable by rubble pitching laid at slopes of 1.5 or 2 to one and with thicknesses varying from 300-500mm. Where stone is not procurable, fascine aprons or mattresses formed of brushwood or vertiva grass may be utilized or reinforced concrete slabs in various forms could be employed.

4.8. Channel Training Works

The satellite photographs show areas of instability and eccentricity in the river channels. These observations are confirmed by studies carried out by Trethowan (1981) in which it was observed that the banks of the river required considerable reinforcement. The reinforcement would be in the form of longitudinal dykes, walls, embankments of timber, stone or concrete, fascines or other material built up so that the channel can be rigidly confined. There is a general tendency of the river channels to form a series of deep water pools on the concave side of bends and anabranches. Shoals can be observed at points where the current passed from one side of the bend to the other. A judicious system of training walls to maintain the natural sequence of these deep pools at the same time suppressing any unduly sharp bends awkward to navigations seen as the possible solution.

4.9. Gorges of the Zambezi River

Four paradigms apply in the geomorphology of the Zambezi basin. These are broadly classified as; historical, structural, functional and climatic geomorphology.

The historical or evolutionary geomorphology of the Zambezi is described by various writers and an interesting one is that by Cecil Keen (2000) who referring to the Upper reaches of the Zambezi stated;

“For 1200 kilometers the river flows rather lazily over the surface of a vast sheet of lava which forms the plateau of Central Africa.”

The description suits the appearance of the river in the upper reaches as is seen on satellite photographs.

Thereafter the river suddenly changes where it reaches a series of cracks in the sheet of lava that lies directly across the course of the river.

The lava sheet is estimated to be 300meters thick and that historically the cracks in it were narrow and filled with soft earth and broken rock which the river leisurely scoured out to shape its course until it found the lowest of the cracks. The effect of this is observed as the excavation of a deep trench cutting across the flow of the river i.e. the Victoria Falls and its gorges. At this point the river is seen to tumble into a trench and then to find its way again. For some time the water goes through chaotic rising and falling leading to the area of Batoka and Devils gorge. Along the full width of its course the river is seen to tumble into deep trenches in a wild disorder and then to find its way out through narrow gorges. This remarkable series of erosion is repeated in eight successive parallel cracks, at each crack, it is claimed, the river has gone through processes of transformation over a period of 500000 years.

Structural geomorphology along the Zambezi River is clearly visible when one studies some examples of the features found in the basin. These features were initiated by major tectonic movement and later modified by weathering and erosion. Recent studies carried out under the auspices of SADC and Zimbabwe River Authority (ZRA) have shown that most of the Zambezi basin is high plateau land of the

Ancient Gondwana Continent with elevations of the high plateau varying between 800metres and 1450 meters HAMSL.

The most extensive areas lie between 1000metres or above 1500meters HAMSL. The fact that there are these elevations differences and that most of the basin is above 1000metres contributes to the high hydropower potential of the basin.

Satellite pictures provide very accurate datum variations along the river.

Climatic geomorphology which as the name suggests focuses on climate as the fundamental influence on the form of the landscape in the basin. The central idea in the paradigm is summarised by the formulation reality model linking inputs (climate) to geomorphic processes (weathering, transportation and sedimentation) that lead to some recognizable output in the form of landforms and landscapes

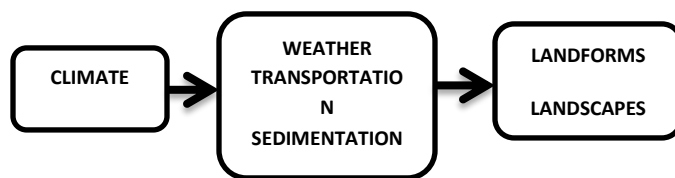


Figure 1. xxx

The apparent influence of climate on landforms is highlighted in the angularity of the land forms e.g. the gorges, faults, rapids, pools and gently rolling plains and landscapes found in the basin. The argument of climatic geomorphology is simply that exogenic processes such as

weathering and erosion are direct results of climate and sunshine.

Functional or dynamic Geomorphology is the fourth and last paradigm which has affected within a short geological timeframe the interaction between form and process within the basin. By focusing on practical problems the concepts of functional geomorphology can be used to contribute to the study and solution of practical problems concerning the behavior of the Zambezi River and its overland flow, its impacts on roads, bridges and other human structures which are highlighted by critiques of hydropower development on this river system

4.10. Integrated Water Resource Management Strategy

The first integrated approach to river management was that between Zambia and Zimbabwe and is enforceable through the Zambezi River Acts. No. 17 & 19 of 1987 of Zambia and Zimbabwe respectively. The agreement is only applicable to the two countries only.

The Zambezi River Authority strategy is focused on expanding its hydro electricity generation potential by the development of seven additional hydro electricity generating dams at Katombora (between Kazungula and Victoria Falls), Batoka Gorge, Devils Gorge, Mupata gorge, Mupanda Uncua, Boroma and Lupata

Regional cooperation in the Zambezi has made considerable progress with the main accomplishment so far being the setting up of the Zambezi Water Commission (ZAMCOM)

Agreement. There is now a broad and important agenda for regional cooperation in particular on synchronizing water resource development plans, revising reservoir operation so as to serve a wide variety of functions such as: flood control, support for flood plain agriculture, river and estuarine fisheries, navigation, cooperation in the control of aquatic weeds and development of climate change adaptation strategies appropriate to the Zambezi basin.

4.11. Contemporary Theories on Zambezi Navigation

The Zambezi River covers about 2500km, over which it drops from about 1400 metres above sea level to sea level. This drop in level gives the Zambezi Profile a one directional fall which does not make sailing upstream possible at certain locations, therefore making navigation cumbersome which can only be overcome by use of locks and localized navigation in backwaters behind water impounding structures, use of ship lifts, gantries or man-made by-pass water fed canals or channels.

In more recent times various academics, design engineers, developers, and regulatory agencies in the SADC region interested in either designing new dams or canal systems or rehabilitating existing ones have expressed an interest in exploiting the Zambezi River further.

These experts have come up with the rational approach to channel or canal design, and basic theories describing channel hydrodynamics and dispersion which include guidelines for channel design, site surveys, canal design elements, and

a procedure for evaluating existing or proposed canal networks that can uplift this technology.

Development of navigation has also to take into serious consideration, economic and environmental concern such as disaster risk management, climatic and ecological concerns.

5. CONCLUSION

Navigation can be extended or developed further than what it is on the Zambezi River to make it the sea route to the Indian Ocean for the SADC countries that share its basin.

Like any other major rivers of the world Zambezi is characterized by all if not most geomorphic features such as Anatomized Meanders, Avulsion Sections, Anabranched Channel Patterns, Braided Meander sections, Irregular Meanders Man Made, Impoundments, Mid-Stream Islands, Natural water falls, Rapid Sections, Regular Meanders and fluctuating grades. This means therefore that the river channel and delta area can be improved by the development and adoption of marine and civil engineering technologies such as channel training walls, dredging of the river bed, rock blasting, earth reinforcement, levy construction, construction of by-pass canals, locks and gates. Further to this a series of concrete arch dams, locks, gates and other hydro infrastructures along its channel can lead to better management of its basin water balance.

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REFERENCES

- Aber, J.S. (2009). Canals and Navigable Rivers, USA.: Emporia State University
- Aber, J.S.(2009). River Systems of the World, USA.: Emporia State University
- Acreman, M.C. Farquharson, F.A.K., McCartney, M.P., Sullivan, C., Campbell, K., Hodgson, N., Morton, J., Smith, D., Birley, M., Knott, D., Lazenby, J., WinΔSgfield, R., and E.B. Barbier.(2001).
- Managed flood releases from reservoirs: issues and guidance. Report to DFID and the World Commission on Dams. Wallingford, U.K.: Centre for Ecology and Hydrology.
- Anderson, J.E. (1984).Public Policy Making (3rd Ed.). New York. Holt Rinehart and Winston.
- Bannister, A. and Raymond, S. (1988). Surveying. Singapore. Longmans Scientific& Technical.
- Baker, V.R. and Twidale.(1991). The Re-enchantment of Geomorphology. Geomorphology. Vol. 40 488-494/
- Barke, M. and O'Hara, G. (1991). Third World Diversity and Interdependency. Essex. Oliver and Boyd.
- Baxter, R.M. (1977). Environmental Effects of Dams and Impoundments. Annual Review of Ecology and Systematics 8.255-83.
- Beanlands, G.(1994).Scoping methods and baseline studies in E.I.A.in Wathern. New York. Routledge.
- Beilfuss R. and Santos de, D. (2001). Program for the Sustainable Management of Cabora Bassa Dam and the Lower Zambezi.International Crane Foundation. USA.
- Bella, S.G. and Minchin, D.(2009). Snakes and ladder-Navigable Waterways as invasion corridors. Israel. : National Institute of Oceanography.
- Bell, M. (1996). Contemporary Africa Development-Culture and the State. London. Longmans.
- Benson, C. and Twigg, J. (2007).Tools for mainstreaming Disaster Risk Reduction.Switzerland, : The Red Cross, Red Crescent Society Geneva
- Biswas, A.K. and Geping, Q. (1987). Environmental Impact Assessment for Developing Countries.London.Tycoon International.
- Blackley, E.J. (1989). Planning Local Economic Development Theory and Practice.Newbury Park.London-Sage.

- Blyth, F.G.H. and Freitas de, M.H. (1992). A geology for Engineers. Edward Arnold. London.
- Brundtland Report .(1987). Oxford.Oxford Press.
- Chenje, M.(2000). State of the Environment Zambezi Basin.Harare.SADC/IUCN/ZRA/SARDC
- Dale, P.(1994). Hydrological Flow Trends as a Factor in Regional Electricity Operation and Planning. R.S.A.CIGRE
- Conyers, D. and Mlalazi, A. Kariba Whose Town? Regional; Dialogue.Vol. 16 No.2 pp119-43.
- Cunningham, B. (1943). Navigable Waterway.The Engineers Year Book 1943. Morgan Brothers. London.
- Dixon, R.E. and Kegan, P. (2005). City, Region and Regionalism. London.Routeledge.
- Dixon, S.A. Carpenter, R.A. Fallon, L.A. Sherman, P.B. and Manipomoke, S. (1992).Economic Analysis of Environmental Impacts of Development Projects. Manila. Earthscan Publication.
- Douglas, J.F. (1986). Solving Problems in Fluid Mechanics. Longmans Publishing . Singapore.
- Euroconsult and Mott Macdonald. (2008). Integrated Water Resource Management Strategy For Zambezi River Basin. Lusaka. SADC-WCD/Zambezi River Authority.
- Finlayson, C.M. and Moser M. (1991).Wetlands.InternationalWaterfowl and Wetlands Research Bureau.Slimebridge.
- Forster, S.F. (1993). Transboundary River Basin Management in Southern Africa.Transboundary River Management and Sustainable Development Proceedings. Vol.1 UNESCO/IHP 195-201
- Fuggie, R.F. and Rabie M.A. (1992). Environmental Management in South Africa.Johannesburg. Juta.
- Garland, G.D. (1996) (ed). Continental Drift.Toronto. University of Toronto.
- Green, W. and Clough, D. (1982). Regional Problems in Policies.Aldershot. Gower Publishing Company.
- Hirsch, A. (1980). The baseline study as a tool in Environmental Impact Assessment.Washington DC. Council of Environmental Quality and Fish and Wild Life Service Department of the Interior.
- Horton, R.E. (1945). Erosional Development of Streams and Their Drainage Basins-Hydrophysical Approach of Quantitative Morphology.Bulletin of The Geological Society Of America Vol 56 : 276-370.
- Hoyle, B.S. and Knowles, R.D.(1993) (ed). Morden Transport Geography.Chichester.John Willey and Sons.
- Isard, W. 1960.Methods of Regional Analysis-An Introduction to Regional Science. New York. John Wiley.
- Kirby, A. and Lambert, D. (1984). The Region. Harlow. Longman.

- Kirkwood, R.C. and Longley, A.J. (1995) (ed) Clean Technology and the Environment. Melbourne. Chapman and Hall.
- Leedy, P. (1981). How to Read Research and Understand it. New York. Macmillan.
- Lemon, A. and Rogerson, C.M. (2002). Geography and Economy in South Africa and Its Neighbours. London. Ashgate
- Lister, I.A. (1967). African Landscape Studies. Salisbury. Collins.
- Living With Risk. (2002). A global review of disaster reduction initiatives .Geneva. ISDR
- Madamombe, E.K. (2004). Zimbabwe Flood Management Practice-Selected Flood Prone Areas. Harare. World Water Meteorological Organization, Global Water Partnership and ZINWA Research and Data Department.
- Mazurui, A. (1980). The African Condition. London. Longman.
- Manjengwa, J. and Stiles, K.G. (1994). Biogeography. Harare. Zimbabwe Open University.
- McCormic, R. and Dorworth, L. (2010). Protecting Our Water and Environment Resource (POWER)- Impacts of Development on Waterways www.planningwithpower.org.
- Miller, G.T.(1990). Living in the Environment. Belmont. Wadsworth Publishing Company.
- Mitchell, R.L.(1981). The Zambezi River-Can Zimbabwe Have a Port? Technological and Economic Aspects. Harare. The Zimbabwe Scientist Vol.15 No.5.
- Morisawa, M. (1968). Streams: Their Dynamics and Morphology. New York. McGraw-Hill.
- Morrissey, J. (2010). Community Risk Assessment for the proposed Mpanda Nkuwa Hydroelectric Dam .Mozambique. Justica Ambiental, Global Green Fund and Provention Consortium.
- Moore, D.; Dore, J. and Gyawali, D. (2010). The World Commission on Dams –Revisiting the Large Dam Controversy. Water Alternatives Vol3 (2):3-13 retrieved from www.water-alternatives.org
- Munasimgho, M. (1993) Environmental Economics and Sustainable Development. New York. World Bank Paper No.3
- Ngazikazana, P. and Mutuvira, C. (2002). Techniques in Geography and Environmental Studies. Harare. Zimbabwe Open University.
- Ngazikazana, P. and Mutuvira, C. (2002). Techniques in Geography and Environmental Studies. Harare. Zimbabwe Open University.
- Noakes, G.R. (1971). (5th. Ed.) New Intermediate Physics. New York. St. Martin Press.
- Robinson, B. (1991). Modeling the Interaction between Human and Natural Systems. International Social Science Journal Vol.130 632-647.

- Sadar, M.H.(1995). Environmental Impact Assessment. Ottawa. Carleton University.
- SADC.(2008). Revised Protocol on Shared Water Courses in the SADC. Gaborone.SADC Secretariat.
- Saha, S.H. and Barrow, C. (1981) River Basin Planning-Theory and Practice. Chichester.Wiley.
- SARDC-IUCN.(1994). State of the Environment in South Africa. Oxford. Oxford University Press.
- Scott, W.R. (1913). The Americans in Panama.New York. Staller Publishing Company.
- Scudder, T. (1996). Kariba Dam's Operation Noah Re-Launched. Harare. Zambezi River Authority.
- Seddon, G. (1996). Thinking Like A geologist-The Culture of Geology. Australia Journal of Earth Science Vol. 43 487-497.
- Simon, D. (ed.) (1990). Third World Regional Development- A reappraisal. London. Paul Chapman.
- Sindiga, I. (1999).Tourism in Sub Sahara Africa –Eco-Tourism Development in Eastern and Southern Africa. Harare. Weaver Press.
- Skempton, A.W. (2009). The Engineers of the English River-River Navigations 1620-1760.United Kingdom.Newcomen Society 1953-54 Volume 29.
- Stock, R. (1995). Africa South of the Sahara- A Geographical Interpretation. London. The Guildford Press.
- Thomas, M.F. (1974) .Tropical Geomorphology. London. Macmillan.
- Thompson, J.R. and Hollis G.E. (1995). Hydrological Modeling and SustainableDevelopment of the Hadeja-Nguru Wetland. Nigeria. Hydrological Science Journal 40(1):97-116
- Thorne, C.R. (1990). Stream Reconnaissance Hand Book- Geomorphological Investigationand analysis of River Channels. UK. John Wiley and Son .
- Trethowan, M.J. (1981). The Zambezi River: Can Zimbabwe Have A Port? Technical Feasibility.Harare. The Zimbabwe Scientist News Vol.15 No. 5.
- Tourbier, T.J and Westmacott, R. (1981). A Handbook for measures to protect water resources in land development.Washington DC. Land Institute.
- Tumbare, M.J. (1994). Cyclic Hydrological Changes of the Zambezi River Basin .Effects and Mitigation Measures.Kariba.Zambezi River Authority.
- Twidale C.R. (1976). Analysis of Landforms. New York. John Wiley and Sons.
- UNEP. (1999). UNEP Global Environmental Outlook 2000. New York. UN Environmental Programs.
- Waterston, A. (1965). Development Planning - Lessons of Experience. Baltimore. John Hopkins Press.

Wathern, P. (1994). Environmental Impact assessment Theory and Practice. New York. Routledge.

Watson, D. (1990) .Explanations and Prediction Geology. Journal of Geology Vol. 77 488-494

Wikipedia.(2010). Panama Canal. Retrieved from "<http://en.wikipedia.org/wiki/Zambezi>"

World Bank. (1994). Environmental Assessment Sourcebook. Washington DC. Environmental Department The World Bank.

World Commission on Environment and Development (2006). Our Common Future.Oxford. Oxford University Press.

World Meteorological Organization. (2004). Integrated Flood Management Case Study- Zimbabwe Flood Management Practices. Harare Global Water Partnership.

Young A. (1972). Slopes. Edinburg. Oliver and Boyd.

Zambezi River Authority.(2005).An Overview. Lusaka. ZambeziRiver Authority.

Zambezi River Authority. (2006). Annual Report and Accounts for year ending 2006. Lusaka. Zimbabwe River Authority.

Zhakata, W and Makarau, H. (2007). Harare. Zimbabwe Open University Meteorology and Climatology.