ADVANCEMENT PLANS FOR REVITALIZATION AND DEVELOPMENT OF ANKOBRA RIVER BASIN IN GHANA

A DISSERTATION

Submitted in partial fulfillment of the

Requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

WATER RESOURCE DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I hereby certify that the work presented in this **Seminar** entitled, "**ADVANCEMENT PLANS FOR REVITALIZATION AND DEVELOPMENT OF ANKOBRA RIVER BASIN IN GHANA", submitted** in partial fulfillment of the requirement for the award of the degree of Master of Technology in **Water Resources Development and Management (WRDM)** submitted in the Department of Water Resources Development and Management (WRDM) Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during the period from Jul, 2017 to May,2018 under the supervision of **Eng. S.K. SHUKLA, (Adjunct Faculty) Department of Water Resources Development and Management, Indian Institute of Technology Roorkee (India) and Dr. Thanga Raj Chelliah, Assistant Professor, Department of Water Resources Development and Management, Indian Institute of Technology Roorkee (India).**The matter contained herein has not been submitted by me for award of any other degree.

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CERTIFICATE

The under design is to certify that this dissertation has been duly supervised and assessed in accordance to laid down guidelines of Department of Department of Water Resources Development and Management, Indian Institute of Technology, Roorkee (IITR) and therefore recommend for acceptance.

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ABSTRACT

Illegal small-scale mining famously alluded to in Ghana as 'Galamsey' has been uncontrolled for a considerable length of time. Although ASGM offers economic benefits and employment opportunities to about 4.5% of the Ghanaian populace, its impact on human health has led to a high incidence of health hazards, deforestation, pollution and loss of biodiversity.

Law Enforcement agencies, Forestry Commission, MoFA, Fisheries Commission, Local Governments, EPA, Standards Board, Minerals Commission and WRC are the Relevant State Institutions of Ghana in collaboration with NGOs and other stakeholders are struggling for the control and management by enabling policy and legislative framework coupled with the right incentivisation along with alternative sources of employment generation to the masses.

This study identifies the current challenges faced by the Ankobra River Basin and its environment in the Tarkwa Nsuaem Municipality and suggests measures for advanced plans for revitalization and development of the Ankobra River Basin to be improved tremendously.

In this regard, this research adopted the technique of Land Use/ land cover changes happen by the modification of the regular scene through both anthropogenic activities and characteristic procedures Analysis of satellite images to distinguish land use/land cover changes depends on the presumption that the recorded electromagnetic radiation, which is the premise of ordering land covers, is modified as the land use/land cover of the same geographic territory changes

Post-classification comparison, spectral-temporal, multi-data classification combined analysis and unsupervised change detection were the consisting classification methods.

Overall, the areal coverage of dark forest and have been reduced between 1986 and 2016, while mining areas and settlements have increased substantially. Dark forest, the dominant land cover, occupied 94.98% of the basin area in 1986, reduced to 93.42% in 2006, decreased substantially again between 2006 and 2016 (92.61%). The area under built-up increased from 2.31% in 1986 to 2.97% in 2006, and further increased again to 3.37% in 2016

In order to obtain indicative data for the study, questionnaires were designed and distributed to a randomly selected sample of 100 individuals within both non-Governmental organizations and Government agencies. Out of the 100 distributed questionnaires, a total of 80 completed questionnaires were returned and then analyzed statistically. The results show that the main

indicators of 0.344 is very poor and needs urgent attention to revitalized and develop the river basin.

Buffer zones positioned close to the source of surface water pollution are therefore more likely to succeed in controlling water quality.

Natural recovery of the river channel, without intervention, is an option where time and space allow and where other limitations, such as excessive water abstraction, are not present.

In terms of hydropower, it is a more secure alternative, Hydroelectric power can be depended upon, availability of green energy, it can be re-utilized, its dependable, it can be directed, it is less expensive, it averts Floods, make available employment opportunities and as tourist attraction sites.

Automation can enhance river revitalization and development through; Decreased Process Variability, Higher Quality Product, Lower Operating Costs, Better Monitoring, Less Machinery Wear, Increased Deposit Yield, Higher Environmental Responsibility, Increased Safety and Overall Process Streamlining.

Thus, Rivers Revitalization Advancement Plan with support to the population for its livelihood is the future to hold the promise of human beings living along the river banks dependent on each other peacefully in nature. The proposed schemes brought in practice will deliver in that direction.

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ABBREVIATIONS AND NOTATIONS

Al Aluminum

As Arsenic

ASGM Artisanal Small-Scale Gold Mining

AU Africa Union

CSQGs Canadian Soil Quality Guidelines

CU Copper

DO Dissolved Oxygen

DEM Digital Elevation Model

EC Electrical Conductivity

EPA Environmental Protection Agency

ERL Effect Range Low

ERM Effect Range Median

ETM Enhanced Thematic Mapper

FAO Food and Agricultural Organization's

GIS Geographical Information System

GLCF Global Land Cover Facility

GREL Ghana Rubber Estate Limited

GWCL Ghana Water Company Limited

Hg Mercury

IRENA International Renewable Energy Agency

IWRM Integrated Water Resources Management

ISO International Organization for Standardization

LEL Lowest Effect Level

LULC Land Use and Land Cover

MET Minimal Effect Threshold

MoFA Ministry of Food and Agriculture

Mn Manganese

NGOs Non- Governmental Organizations

NWP National Water Policy

PECs Probable Effect Concentrations

PEL Probable Effective Level

RBBs River Basin Boards

SEA Strategic Environmental Assessment

SEL Severe Effect Level

SMFP Sustainable Fisheries Management Project

SOG Survey of Ghana

TECs Threshold Effect Concentrations

TEL Threshold Effect Level

TET Toxic Effect Threshold

TDS Total Dissolved Solids

TOC Total Organic Carbon

USGS United States Geological Survey

UN United Nations

WRC Water Resources Commission

WSSD World Summit on Sustainable Development

WSSDP Water Sector Strategic Development Plan

CHAPTER-1

INTRODUCTION

1.1 BACKGROUND

Other than normal flow of a river, anthropogenic effects influence lithology, geography and superficial water quality including land use [1][2][3][4].For an ever-increasing population with more stress on natural resources, [5][6][7] today Africa needs its water more than any other continent[8][9].

Ghanaian Rivers offer eco-friendly and other economic benefits like fish harvesting, irrigation and drinking water source. The perennial river system of Ghana is a living ecosystem, an essential component of the natural hydrological cycle and its continuous clean flow has been the character of its health. In the aftermath exploitation of basin, for various development purposes, combined with disintegration in the quality of the water, causing demand rise as rainfall continue to decline [10], streams experiencing tension or pressure.

Globally, artisanal small-scale gold mining (ASGM) is becoming significantly industrialized, generally run unlicensed, has created jobs for at least 15 million of the rural population directly and about 100 million in rural communities across more 70 countries, reaching beyond Africa Union (WHO 2013) [10]. Numerous ASGM operations emerge close to streams and waterways for simple access to alluvial metals (gold dust found in soil sediments), in addition to disposing of water utilized to stream as a part of preparing and as an acceptable situation for mine processing waters. In spite of the fact that ASGM adds to rural economies, it regularly inflicts ecological, security and social conditions because of the simple mining techniques used [10].

The approaching danger of Ghana's water assets running dry in the years to come gets scarier by the day. Progressively, water treatment plants are being closed down. This is due to the contamination of the rivers by illicit gold miners' discharges in the stream and damaging the environment.

Illegal small-scale mining famously alluded to in Ghana as 'Galamsey' has been uncontrolled for a considerable length of time.

The aquatic lives in the Ankobra River Basin are subjected to significant pressure from the quality of water, inadequate solid waste management and lack awareness on environmental issues.

Even though the ASGM has economic and job benefits of about 4.5% of the population, its effect on human health, environmental health, deforestation, pollution and biodiversity is quite high.

Galamsey' has added to:

- shrinkage of forests leading to farm cultivation (illegal farming over forest reserves),
- Illegal settlements within forest reserves,
- Wildfires and unscrupulous tree felling by chainsaw operators loggers, timber users for forest yield extraction,
- Indiscriminate reaping of trees unconcerned to forestry sciences,
- Free-range cattle ranching,
- The preponderance of prominent plant species which colonize clearings and prevent characteristic recovery of local tree species.

Additionally, various other types of pollutants adversely impact the quality of river stream water which could be in general nutrients pollution, surface water pollutant, oxygen depletion, ground water pollution, microbiological pollutants, suspended matters, chemical pollutants, spilled oil in water, sewage and waste water disposed etc. Due to mining activities, increased agriculture, inhabitation around river and growing industrialization in and around Ankobra basin, many of such pollutants are affecting the basin.

RELEVANT STATE INSTITUTIONS OF GHANA

To overcome the menace stated, many governmental institution like Forestry Commission, Law Enforcement agencies, Local Governments and others etc. in collaboration with NGOs and other stakeholders are struggling for the control and management by enabling policy and legislative framework coupled with the right incentivisation along with alternative sources of employment generation to the masses.

It is realized that self-supporting stream frameworks give imperative natural, social and services to human [11][12]. In urban settings, River revitalization has its principle concentrate as lateral restoration including tributaries affect the flow regime of the River thereby expanding the level of an opportunity of the stream. Restoration of urban Rivers is a challenge for water resources managers, researchers, experts, and citizens. [11]

In April of 2017, the legislature of Ghana began the way toward recovering an expected 1.5 per cent of the nation's territory surface which has been debased by illicit mining and other ruinous natural occurrences. The nation's landscape space is evaluated at 238,000 square kilometres. Out of this, in the vicinity of 50,000 and 60,000sq km, (> 21%) signifying 1.5 percent, is apparently ruined (non reclaimable) by such practices.

The Minister of Lands and Natural Resources, Mr. John Peter Amewu, who reported this, said work had just begun on the recovery practice by the levelling of the land in the debased territories. “Mining on waterways, burrowing of riverbeds and debasing nature is criminal and deserving of law; and the laws will be pragmatic with suitable approvals," he showed.

To recover and reestablish the lost vegetation to the locales will allegedly cost a huge sum of cedis (GH ₵) in light of the level of degradation. (*https://revitalizationnews.com/article/ghana-launches-effort-restore-landscapes-rivers-damaged-illegal-mining/*)

Other than such appalling occurrences, unlawful mineworkers have caused and keep on causing unsalvageable devastation to nature particularly waters bodies which fill in as wellsprings of water for local, modern and water system purposes. Mercury has standout as a major contaminant for both the soil and water bodies, different chemicals with slime, demolition ranches and homestead, land and vegetation degradation, deforestation, biodiversity extinction, infringement of woodland and amusement is the order of the day because of the unlawful nature of the Ankobra River mining.

1.2. RIVER BASINS IN GHANA

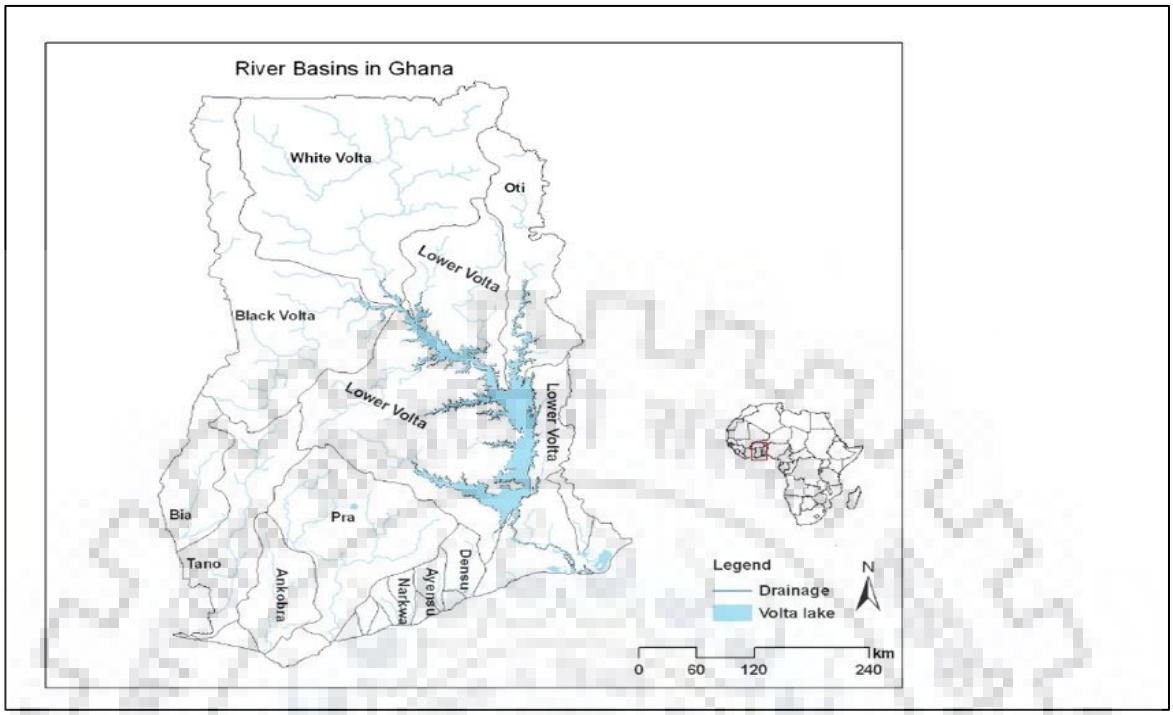

Figure 1.1 *River Basins in Ghana*

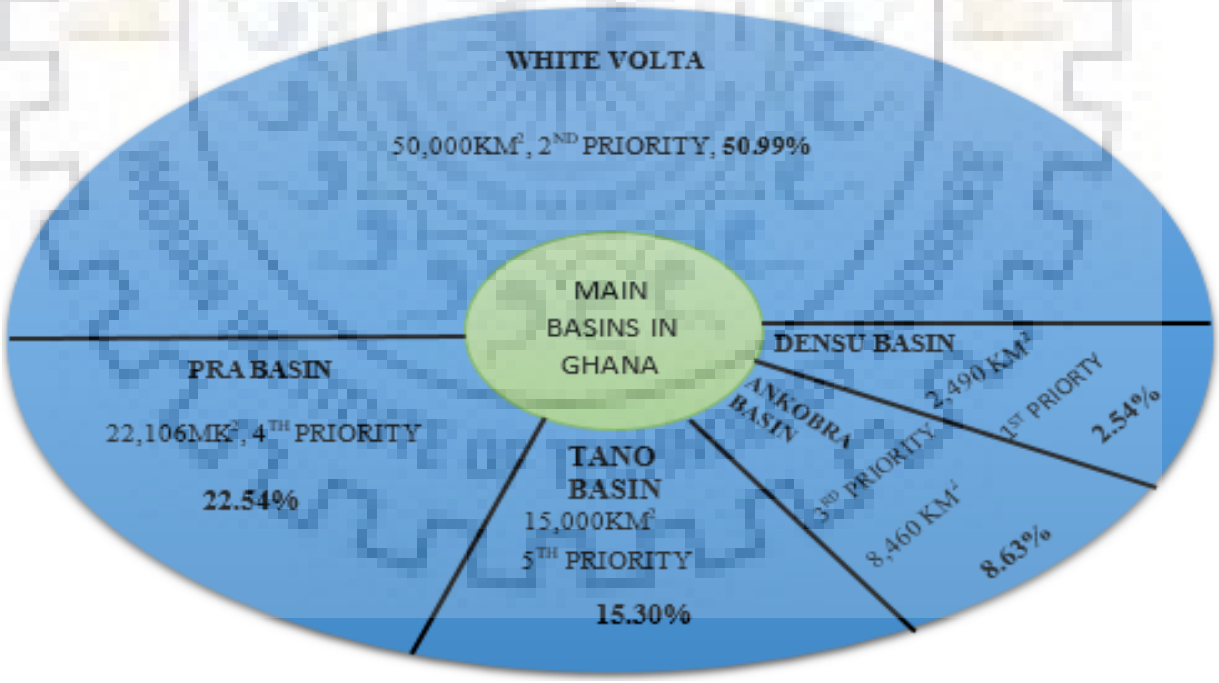

Figure 1.2**:** *Basins in Ghana* [13]

1.2.1. Ankobra Basin

Plate 1.1*: *Original state of Ankobra River Basin (picture was taken, 1998)

The determination of Ankobra River Basin as the third largest basin, behind Densu and White Volta Basins separately, the execution of IWRM by WRC, is a reaction to flow and rising open worry on the effect of mining exercises on group employment, human wellbeing, quality water, accessibility, and financial advancement.

IWRM, an efficient procedure for practical advancement, portion, and checking of water asset use with regards to social, financial and natural destinations. This depends on the understanding that water assets are a vital segment of biological system, characteristic asset, and socio-economic goods.

1.2.2. STANDARD DESCRIPTION

1.2.2.1. *Socio-economic features*

The Ankobra River courses through the tropical, evergreen, wet timberland in the southwestern segment of Ghana. On account of the expanding pulverization of vegetative cover and vast scale mining exercises, the exploitation of nature has turned into a vital worry in the basin. In spite of the fact that dry spells seldom happen, the expanding exploitation of the surface water assets inside the basin is probably going to accelerate deficiencies for generation of consumable water in the perspective. Groundwater-based water supplies, thusly, are probably going to keep

on being abused as the primary asset for the arrangement of consumable water to the riparian zones.[14]

1.2.2.2. *Locality and geography*

Ankobra River Basin is classified on longitude 1° 50' W and 2° 30' W and latitude 4° 50' N and 6° 30' N. The basin is constrained toward the east by the Pra Basin, the north and west by the Tano Basin and in the south-east by the little shoreline front Butte Basin. The basin has a place in the physiographic zone called the Forest Plateau.

Numerous times of escalated disintegration have diminished the region to a fairly consistently showing up level by and large at a height of 250-300 meters above ocean level. The overwhelming precipitation in the basin and ensuing timberland vegetation, which averts sheet disintegration, clarifies the articulated analyzed nature of the level.

The geology of the basin is described in the southern portion of moderately level land, which gives route in the mid to northern segments of the basin to typically adjusted slopes, which sporadically are additionally steep-sided. The bumpy landscape is unmistakable around Wassa Akropong, a chain of hillocks framing the north-eastern edge of the basin, south of Dunkwa and north of Awaso in the upstream north-western corner of the basin. The sloping landscape achieves an elevation of near 500 m above sea level.

The Ankobra River Basin is a piece of the Western River System and spreads a locale of around 8,460 km^2.The stream takes its source from the slants north of Basindare (near Bibiani) and streams fittingly 260 km generally due south before it enters the Gulf of Guinea at Asanta two or three kilometres west of Axim.[14]

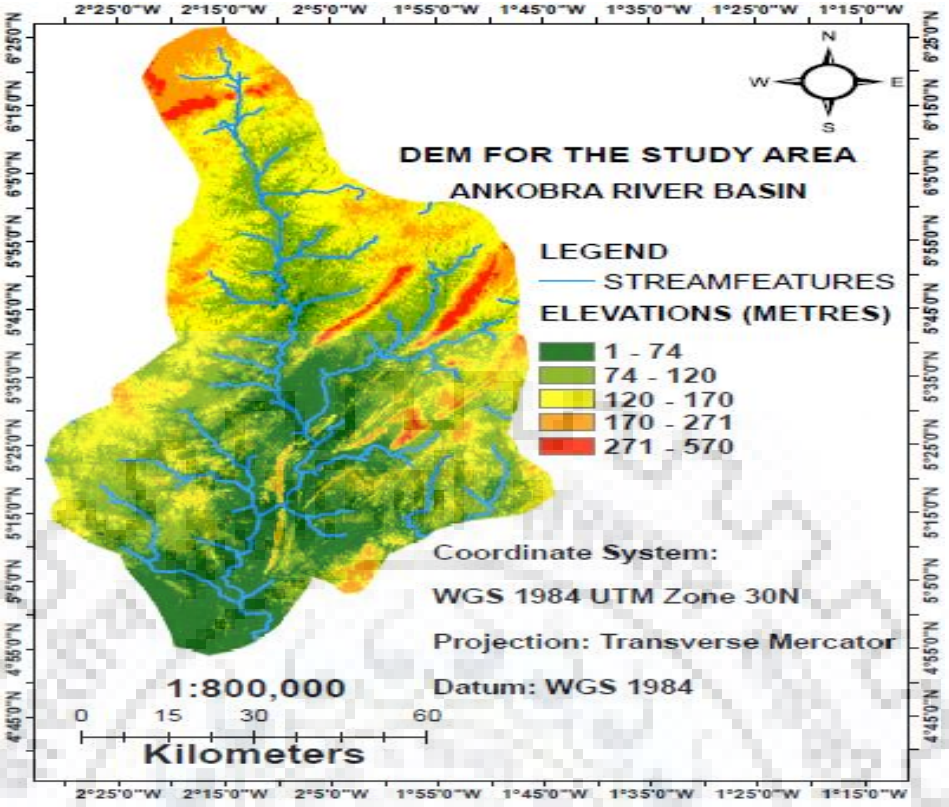

Figure1.3: DEM for Ankobra River Basin

1.3 SCENARIO IN GHANA

***Figure 1.4**: Management Water Resource in Ghana* [13]

The IWRM, formed in the mid-1990s, principally support the fundamental politic, institutions and regulatory structures in Ghana. Some remarkable projects and activities as of now set up are the WRC established by an Act of parliament in 1996, dynamic inclusion with neighboring nations on trans-limit issues on the Volta Basin.

What's more, significant limit building includes occurred inside the key establishments engaged with water assets administration in the course of the last 14-21 years? [15]

The implementations of the IWRM has experienced reinforcing essential "Empowering Environment" start arranging at basin level, beginning with "water focused on" basins. The lessons learned in executing basin designs give a contribution to promote basin arranging and planning the National IWRM Plan with a role in filling the gaps in the institutions after more fundamental IWRM works as of now is actualized with lessons learned.[15]

The IWRM Plan might found with regards to the general improvement arranging and specifically the water segment arranging in Ghana. Subsequently, the general arranging system is the shared Growth and Development Agenda of Ghana whose approaches and advancement designs are expounded. The possibility of these plans and frameworks are one of a kind. While the point of convergence of the IWRM part is tied in with legitimate and established administration capacities sections consolidate wander plans for a water change.[15]

1.4 CHALLENGES OF IWRM IN GHANA

The circumstance that Ghana is fundamentally blessed with substantial matched to recent routines and stresses in the imminent. In any case, the accessibility notably from period to period and also from year to year. Additionally, the conveyance inside the nation isn't even, with the southwestern being preferable dampened over the seaside and northern locales. Additionally, the assets are in danger of exhaustion and deprivation, and issues are rising a result of: -

- Unrestrained catchment debasement because of deprived horticultural performs (particularly cultivating laterally waterway banks), populace weight (timberland extraction for relocation and industrialization).
- As a result of pressure from climate variation and climate variability and channel is exceedingly adjustable. Crisp administrations changed bringing about contracting of the assets, and influencing water supply and stream transport. Expanding populace

development and urbanization has likewise set an overwhelming interest ashore, water and other regular assets and incites clashing and contending water uses and contamination.

- Growth in population and urbanization has likewise set an overwhelming interest ashore, water, and other common assets and instigates clashing and contending for water uses and pollution. Albeit much has been done so as to build up the lawful and established structure for the administration of Ghana's water assets, the nation is as yet confronting various difficulties keeping in mind the end goal present and forthcoming. Midst these can be specified:
- An absence of sufficient information and facts on superficial, aquifer amount and in addition water quality;
- Climate variation and atmosphere changeability effects on water and other normal assets are deficiently portrayed and defectively joined in sectoral water administration systems;
- Catchment debasement and poor water quality are because of the unguided exercises inside the basin. (e.g. cradle zone arrangement should be executed);
- Scarce talented HR [15]

The development foremost to the final action programme included a tight collaboration with major stakeholders and national experts. Thus sustainability tests, expert meetings on identified issues, prioritization of issues and actions, and final validation by stakeholders of priority issues and actions[15]

1.5. WHY REVITALIZATION AND DEVELOPMENT

The target of empowering waterway basin administration not restricted to the accomplishment of financial advancement, but rather to upgrade water administration honest and to deal with the growing interest for water supply for medium-and immense size urban territories.

An unimaginable asset is our streams. Urban surroundings pose so much problem such as drought, flooding, pollution and crowding while living with these resources. But opportunity also springs up due to this problems like social concerns, environmentally contaminated lands, inadequate infrastructure, and access problems etc.

The flow regimes restoration of the river as well as the increase of the freedom of the river couple with its banks and its tributaries, and the lateral connectivity is due to river revitalization in the urban environment. The restoration of urban water courses is crucial for managers, researchers, experts, and citizens.[11]

Revitalized rivers will enhance water quality, give green space to accelerate health progress in poor and socially excluded groups, enhance surge assurance and diminish our reliance on imported water, restore a functional ecosystem, enhance river identity, foster civic pride, provision of hydropower, improve the quality of life and focus attention on underused area, and benefit to disadvantaged communities.

1.6. EXTENT OF THE STUDY

Tarkwa-Nsueam Municipality in the Western locale of Ghana characterizes the topographical region where the study was carried out. The Municipality is strategically located along perennial water bodies (rivers, and streams) that could provide a lot of economic opportunities to unfold the development fortunes of the Municipality.

Water resources covered in the study include rivers, streams which are located in the selected Municipality in the region. This means that these and other water resources which are located in the region but outside any of the selected study area were not considered in this study.

1.7. ORGANIZATION OF THE REPORT

This thesis was structured in five chapters. The **first chapter** entails background, river basins in Ghana, baseline description, a scenario in Ghana, challenges of IWRM in Ghana, why revitalization and development, the extent of the study, and report organization. The **second chapter**; displayed a system of Expert Opinion on the Subject issue, Key Water Management Issues, the flow province of Ankobra Basin, Existing Legal Framework, Some Previous Works, Gaps Identified and Objectives of the Work. The **third chapter**; Methodology, Data Collection, and Processing; described the steps to achieve the objectives of the thesis. The **fourth chapter** focused on results, discussions and proposed advanced plans based on land use land cover and questionnaire for revitalization and

development of the river basin. The focus of **chapter five** was on the deduction and commendations.

CHAPTER-2

LITERATURE REVIEW

2.1 EXPERT OPINION

A review of the literature and past studies has been done to know the studies for evaluating the impact of illegal mining on the basin and other factors.

(Phebe Asantewaa Owusu el al, 2016) Water shortage is turning into a noteworthy worry for individuals around the globe and the need to secure the current ones and discover ways or intends to give safe water to people the world over in sufficient amounts with remembering the necessities of who and what is to come.

Water formed the bases of life, connected to loads of direct or indirect services, for example, the well-being of human including the socio-economic, welfare and monetary improvement of a group or nation. Exploring Ghana's water assets management is fundamental.

(Samuel Obiri et.al, 2016) The Ghana economy is benefiting from gold mining with negative environmental and socio-economic impacts on the host groups related to gold mining have dominated these economic increases. This calls for money-saving advantages investigation of mining before new mining leases are allowed by the important experts.

(Paul Beeton Damoah, 2013) Mining activities in developing nations like Ghana, are carried out either legally or illegally, with little or no supervision. The affected water bodies have been impacted base on quality and morphology due to the mining activities along the rivers. In the present investigation, the effect of small-scale mining exercises on the Ankobra River was completed in four groups inside the Amenfi East District of the Western Region, an area where the activity is highly prevalent. Small scale mining has boosted the economy but its activities had caused negative impacts on the environmental structure of the Ankobra River. Reducing the impacts of small scale mining activities, better regulatory laws and enforcement bodies have to be created or empowered to strictly monitor the mining activities.

(M.O. Fashola et.al, 2016) The presence of heavy metals though some are essential for physiological processes in human, their presence in high concentrations can be crucial to human health and have malicious belonging to human wellbeing and biota. Nevertheless, such challenges can be overcome by strain selection and supply of nutrients to support the bacteria growth affect human effects wellbeing and biota.

(B. S. Amaral, et al 2011) In densely populated areas along Acari River basin, the areas available for interventions are limited backed up with numerous socio-economic problems,

making revitalization process very complex, in light of the fact that it includes the need of huge riparian territories, so as to discover space for the waterway recuperate its normal course and flooding zones. In any case, regardless of whether territories reestablished can first conform to the normal condition, overwhelming adjustments bowl endured presumably over time with prompt surges as it happens. Activities within the basin must be considered, that diminish the impermeability and to protect shallow maintenances, with the utilization of stores.

(Mohamed A.E. Abdel Rahman et.al 2016) To decrease the human effect on normal assets and to distinguish a fitting area utilize, it is basic to complete logical land assessments. Such sort of investigation permits recognizing the principle restricting elements for the horticultural generation and empowers decision making to create trim management ready to expand the land efficiency. The improvement of the assorted gathering of soils can be credited to the variety in geography, causing disintegration, filtering, sedimentation and other pedogenic shapes modified by water table.

(B. S. Amaral, et al, 2011) the waterway basin experiences natural pollution, illicit riverine occupations, stream banks disintegration and siltation, which exacerbates surge results. Thinking about the idea of stream renewal, the thesis intends an arrangement that disseminate measures to restore the urban scene along Acari River, utilizing a system of hydrodynamic PC demonstrate, break down the framework conduct amid the event of surges and to conjecture future situations, with surge control measures to revive waterway capacities.

Ractliffe & Reinecke 2002 Rehabilitating the River considers hypothetical dearth of testable with the subsequences of nonappearance principles of rehabilitation. The concept emerging scientific, considers empirical observation to development the test hypotheses, which generate the values for tentatively development.

Odum (1981, cited in Terrill, 1999) portrayed indicate that riparian zones are fundamental assets looking specifically at water and land. Riparian zone rehabilitation takes into account revegetation and encouraging land conservation. **(Petersen *et al*. 1992)** The requirement for riparian zone dictate choose of species **(Javela & Jormola 1998).** The recovery processes not requiring human contributions can be an alternative to river rehabilitation.

2.2 KEY WATER MANAGEMENT ISSUES

Rivers particularly the Ankobra estuarine serve as source of income for rural and urban settlers including livelihood, the extensive utilization of the resources has created pressure on the environment and species. The basin is siege due to mining, logging, cultivation and establishment of settlement.

2.2.1 Bamboos and Mangrove logging

Commercially, mangroves are source of income for some of the communities along the river.

The inaccessibility due to poor road network has trigger the illegal mining activities in the area. The commission charged with the responsibility of managing forest reserves can hardly track the operations of the illegal loggers due to logistical issues.

Plate 2.1 *Depleted mangroves*

plate. 2.2 *mangroves logged being transported illegally*

Plate. 2.3 *Bamboos for Transporting*

plate 2.4 *Illegally Logged Mangroves*

Bamboo cutting serve as income source for rural population and make livelihoods them. The consequences of the economic viability of bamboo lead to complete destruction or extinction

of bamboo along the River. The destruction of bamboo tree affect the ecosystem the impact on they flora and fauna and on the riparian lands. The bamboo that is of no commercial value are set ablaze after they are dried causing bushfire and severely destroying the marine ecosystem.[16]

2.2.2 Settlements along the River Banks

The creation of settlements along the River banks, affect the land cover system and impact the vegetation of the area. Rise in population has led to the expansion of new Settlements and the associated human activities are crucial to the river banks. Proper planning as the population extend to sensitive areas are expected to make development sustainable.[16]

Plate. 2.5 *built -up at Ankobra River Bank*

plate.2.6 *Insanitary Condition at River Bank*

2.2.3 Unimproved Sanitation

Sanitation services, normally unavailable in newly established settlements and areas that are served benefit from inadequate or poor services. The contaminated river is crucial to health and environmental hazards, pollutants generated from community find their way to the river, similarly affecting ecosystem [16]

2.2.4 Plantation Farming on River Banks

This area has commanded a larger portion of land still remain to be covered by the rubber plantation at the banks of the river. The activities have accounted for the prompt growing of croplands and grassland as analyzed by the classifications. [16]

Plate 2.7*: *Exposed land for Rubber Plantation

2.2.5 Ankobra River Illegal Mining

The Ankobra Basin is blessed with huge deposits minerals and support the economy of the country through exported. A lot of investments are geared towards mineral seeking and escalation cost. The biggest mining concessions are arranged for the most part in the mid-eastern bits of the basin for the most part in the area. Excavating exercises with an intelligent result on the biological system inside the basin can be arranged into two gatherings like overwhelming modern mining as rehearsed by the organizations. Gathering the small-scale mining like that directed by privately owned businesses and people either legitimately or wrongfully. Exercises of these mining organizations are not really controlled and directed. As per the WRC, every one of these organizations releases untreated mining gushing specifically into the Ankobra.

This practices have adverse effect on the ecosystems of the Ankobra Basin as the quality of the water is normally affected. Besides, the stream and its tributaries, especially during the dries, significantly affects the greenery related to the overarching the aquatic life. The quality of Water decline and pollution is being identified as the prominent water management. The effluents discharged into the basin (Tarkwa, Beposo, Prestea, Nsuta and Awaso).[16]

Plate2.8*: *Mineral quarrying within the Ankobra Basin

2.2.6 Poor Quality of Water

A study conducted by the WRC indicated that the extent of arsenic transported by the river in 2006 was 18,000 kg/ year. Cyanide is very high in the river. In like manner, one of the noteworthy troubles in the Ankobra River Basin is the outcome of mining practices on the idea of the surface water of the basin. Indeed, even from the layman's perspective, the Ankobra River, especially on the southern seaside, is profoundly contaminated and with the expanding measure of legitimate and unlawful mining, the arsenic levels had tripled in the vicinity of 2006 and 2015.[16]

Plate 2.9: *Polluted River Ankobra due to mining along the river*

If not observed, the substantial scale mining tasks and developing number of unlawful mining exercises inside the bowl have the capability of expanding suspended solids and subsequently the turbidity of the stream. The mining exercises tend to surge the arsenic level in the stream. Expanding the utilization of the waterway for the expulsion of both strong and fluid waste by the riparian groups additionally represents a danger to the nature of water in the stream.[16]

2.2.7 Influence of Natural Causes

The majority of the previously mentioned issues are certifying the confirmation gave by the satellite images and are demonstrating the patterns as they exist at the season of information accumulations. The Landsat information closes in 2010 and the field information is as present as in 2015 showing a period interim of five years. One can just envision the degree of decimation which the Ankobra biological system has endured without satellite information. From 1990, 2010 and 2015, there is sufficient confirmation to show that the Ankobra biological community under genuine dangers. The worry and the route forward ought to give palliative measures to taking care of the issue.[16]

2.3. CURRENT STATE OF ANKOBRA BASIN

***Plate 2.10*:** *Site tour along the Ankobra basin*

Plate 2.11: *Bonsa River with highly turbid:* ***a*** *GWCL treatment plant full of sump;* ***b*** *sedimentation tank of GWCL with highly loaded suspended solid build-up. Picture: A.O. Affum*

It is estimated that Bonsa River is 44km from its source to the conversion of the Ankobra River. At Bonsaso, where mining, processing and beneficiation of gold are basically situated in the stream nearer a community. **Bonsa settlement primary serve as a human settlement with population of approximately 34,941** exceedingly focused local ASGM. It implies harmful component tainting of waterway framework is probably going to affect extreme soundness and admission location for water treatment plant. The Bonsa channels enter the Ankobra River and enter the ocean.

Ghana gold mines can be found on the South-Western part of the country, roughly a zone of around 40,000 km^2.The investigation territory falls inside the tropical area encounters maximum precipitation. The yearly mean precipitation varies between **1500mm and 1933** mm, most extreme precipitation occurs during **March and June**, **October to February intense** dry

weather. It ascends in the bumpy district of Bibiani and streams in a southerly heading to enter the bay only west of Axim. Little specialty can explore roughly eighty kilometres inland from its mouth. Previously, transportation of hardware was carried out to the gold-mining zones around Tarkwa. The westernmost of the three streams, Tano nearer to Techiman is the focal point of the nation. It likewise streams in a southerly bearing, yet it discharges into a tidal pond in the southeast corner of Côte d'Ivoire. The route by steam dispatch is conceivable on the southern segment of the Tano for around seventy kilometres.

Plate 2.12*: *Ankobra Basin

The stones in these districts are as often as possible carbonate-lacking and offer climb to insufficiently cradled water. Likewise, in gold and base metal mining domains, sulfides oxidation happening on account of engineered and biogeochemical shapes prompts the age of low pH ground-water that enables the crumbling of following metals into the groundwater structure in high obsessions. The groundwater, consequently, winds up dangerous for human use.

Beside nearby use, the water resource inside the basin is used for the water framework in tremendous business properties, for instance, the Benso Oil Palm Plantation, Norpalm Oil Palm Plantation and the Ghana Rubber Estates Ltd. Also, the mining association's in like manner hypothetical water for the planning of metal and clean covering.

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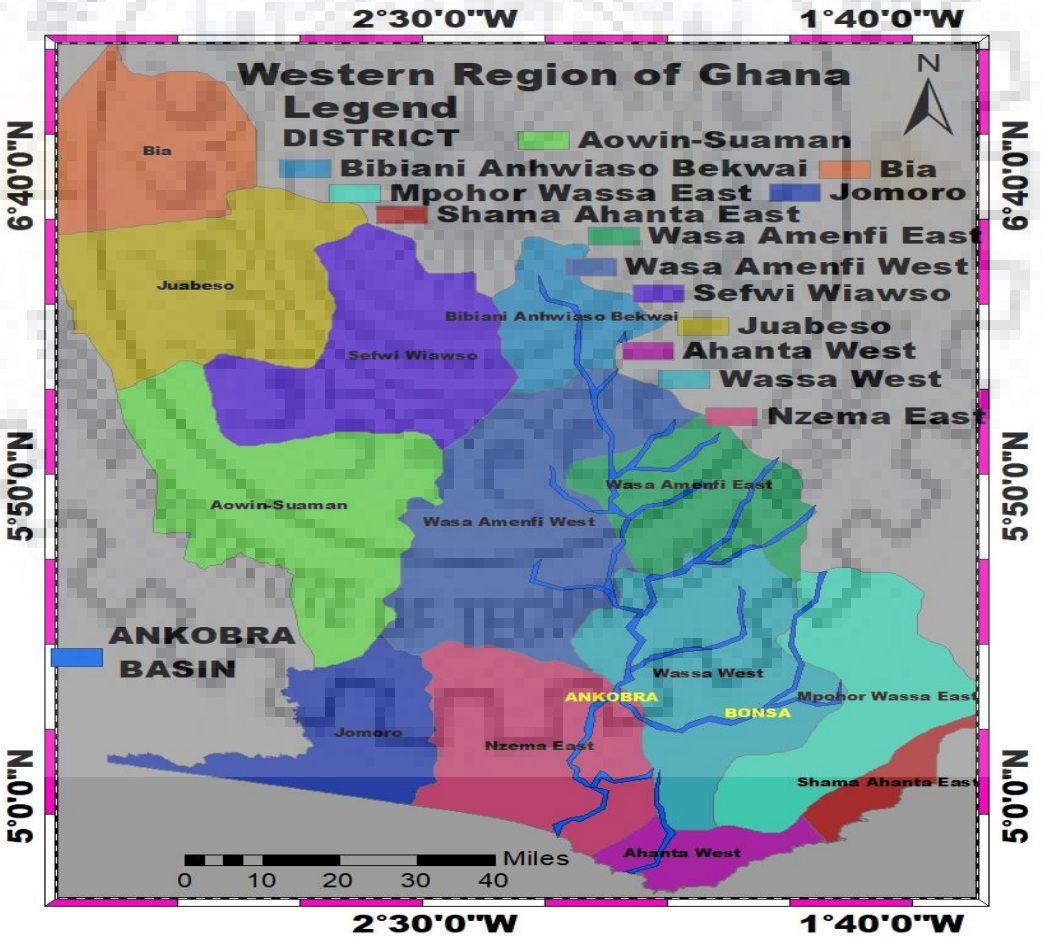
2.3.1. Challenges

The Ankobra Basin is apparently the most misused basin in Ghana as far as characteristic assets.

The principal challenges include:

- Mining activities
- Chain-saw operators
- Forest mining
- Unimproved sanitation in towns along the river
- Excessive erosion
- Skirmishes in Societies on mining

2.3.2. Western Region of Ghana, Districts in the region with Ankobra River Basin.



Map.2.1 *Western Region of Ghana, Districts in the region with Ankobra River Basin.*

In light of the 2000 Population Census5, Table 2.1 present populace in the Ankobra River Basin. The settlement classes depend on the populace edge of 5,000 individuals for urban and under 5,000 for provincial settlements. The segment of a region's rustic populace living inside the bowl is assessed by coordinating the extent of the territory of the separate locale, which is situated in the bowl and utilizing the rates to compute the country populace. The populace increments recorded in the most recent intercensal period. Nonetheless, supplementary locally inside the bowl, considerably sophisticated development acknowledged especially in specific region of the gold mining territories, that demonstrated development degrees of over 10% amid that era.

Interior movement is the utmost critical factor of this stamped populace development. As the territories are ending up moderately alluring for vagrants, new pioneers are probably going to incline toward the areas to swell up the current populace. The main impetus overdue this marvel is quarrying – both huge scale and "galamsey" activities – yet in addition, the cocoa and elastic ranches, and the timber business, when all is said in done, can clarify this pattern.

As a normal on the entire area, the populace thickness was given as 80 pop/km^2 when contrasted with the general national normal figure of 77 pop/km^2. The aggregate populace (the year 2000) living inside the bowl was 685,000 of which the inner-city populace instituted somewhat fewer than 20%. Statistic highlights determined at region close are likewise exhibited in Table 2.1

Table 2.1**:** *Demographic Features* of *Ankobra River Basin (Census-2000)* [14]

Region	**District**	**Settlement category**	**Population (2000)**	**Area in basin (km^2)**	**(%)**	**Density (pop/km^2)**
Western	Bibiani-Anhwiaso-Bekwai	rural	60,800	646	7.6	118
		urban	15,200			
	Wassa Amenfi West	rural	104,500	1,575	18.6	66
		urban	0			
	Wassa Amenfi East	rural	108,900	1,640	19.4	71
		urban	7,400			
	Wassa West	rural	149,700	2,325	27.5	100
		urban	82,600			
	Mpohor Wassa East	rural	25,000	384	4.5	65
		urban	0			

	Nzema East	rural	67,500	1,343	15.9	66
		urban	21,800			
	Ahanta West	rural	2,000	35	0.5	57
		urban	0			
Central	Upper Denkyira	rural	24,800	402	4.8	62
		urban	0			
	Twifo-Heman / Lower Denkyira	rural	800	15	0.2	53
		urban	0			
Ashanti	Atwima Mponua	rural	9,000	95	1.0	95
		urban	0			
Ankobra Basin, total		rural	553,000	8,460	100.0	80
		urban	127,000			

2.3.3. Socio-economic profile

The centre occupation inside the bowl is farming, which utilizes around 65% of the whole populace. The standard of the general population live in provincial groups and enjoy cut and consume or moving development on a subsistence scale. Notwithstanding, numerous organizations and also people in the bowl possess cocoa, citrus, oil palm, coconut and elastic estates.

In the urban areas, the economic activities are more diversified and the prominent occupations include wholesale and retailing, manufacturing and other commercial activities. The small-scale industries include sawmilling, block making, local soap manufacturing, blacksmith and metal work. Many large markets, such as those at Tarkwa and Sefwi Bekwai form points of contact between rural and urban residents.

The above socio-economic pattern is highlighted in Table 2.2. The figures in the table are derived from the 2000 Census data and are given as percentages of the economically active population (above 15 years of age). In spite of the important status in a national economic context, it is worthwhile noting that the mining sector only occupies a reasonably small portion of the basin's population.[14]

Table 2.2**:** *Active economic population % (a)* [14]

Economic activity (industry)	District					
	Mpohor Wassa East	Nzema East	Bibiani-Anhwiaso-Bekwai	Wassa West	Upper Denkyira	Wassa Amenfi East and West
Agriculture and forestry	67.0	75.6	45.8	70.8	54.2	65.3
Angling	1.3	1.5	0.5	0.4	1.4	1.8
Extracting minerals	3.8	1.1	11.2	2.5	6.8	1.7
Industrialized	9.8	4.2	9.9	9.0	9.5	8.8
General sales	3.8	5.2	13.1	5.6	9.1	7.8
Structuring	2.2	1.3	4.9	2.4	4.7	1.9
Guesthouse and eatery	0.8	0.3	2.4	0.6	2.9	1.3
Transport and communication	3.2	1.6	2.7	2.2	2.3	2.2
Education	3.6	3.0	3.3	3.2	3.2	3.7
Other (unspecified) activity	4.5	6.6	6.2	3.3	5.9	5.5
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

(a) *Only districts with a sizeable population within the basin are included in this table* [14]

2.3.4. Land use design and biological pattern

The masses of individuals living in urban territories around the globe is anticipated to develop from 3.15 billion of every 2008 to 9.6 billion by the year 2050 [18]. As urbanization builds, the populace weight will make it hard to give administrations to individuals living in urban zones and numerous individuals in the developing scene won't approach the consumable water, sanitation and safe living circumstances. It is thusly evaluated that half of the general population living in the creating scene need access to these administrations as of now [18]. The developing rate of deforestation in Africa [18] for instance, will impact sly affect the jobs of

individuals, who basically rely upon the normal assets for their improvement, while the indigenous habitat will be lessened because of the arrangement of merchandise and ventures. The need to, in this manner, design and oversee arrive utilize and water assets viably in Africa

It now opened up in spite of its poorly developed and thinly populated due to the location of the extractive industries. As such a drastic change in the ecological prospect within the Ankobra basin for the past 10-20 years. A quick decrease in timberland cover because of stamped moves in arriving utilize caused by expanded agribusiness and mineral extraction.

The wet evergreen forest sub-zone of the Ankobra basin is found mostly in the southern downstream section. It has moderately poor soils and in this manner isn't alluring to cocoa agriculturists. The zone is however overwhelmed by manors of elastic trees, oil palm and coconut palm. All the mineral deposits produced and exported from Ghana comes from the Ankobra Basin.

Thus, much speculation has disappeared into mining chasing and quartz abuse a relentless increment in the activities to the detriment of a quickened rate of deforestation and contamination. Mining businesses are found for the most part in the mid-eastern bits of the basin. Water assets inside the Ankobra bowl are under attack possessed to the different points of view. From comparative picture maps speaking to the year 1990, Table 2.3 outlines the improvement of territory scope of the forested and arable grounds as it has happened amid this ten-year time frame.

Table 2.3*: Ankobra Basin land use/land cover development (1990-2000)*

Year	Forest reserves	Forested areas with dense tree cover	Arable land	Settlements and unclassified areas
1990	25%	55%	15%	5%
2000	15%	35%	40%	10%

(Water Resources Commission, Ghana, Ankobra-IWRM-Plan-Final- March-2009)[14]

2.3.5. . Aquatic Assets

2.3.5.1. *Meteorological physiognomies and effect on environment*

Data concerning the meteorological conditions are obtained from the Ghana Meteorological Agency, which operates a quantity of rainfall locations in the Basin.

***Table 2.4**: Average periodic rainfall (mm), Tarkwa (1970-2007)* [14]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1776	35	80	139	165	251	290	144	67	155	224	154	72

Rainfall in the basin is high in both spatial and temporal distributions. Between 90 and 140 days, are the main annual rainy days- shown by the meteorological statistic.1450 and 1950mm are the ranges of the annual rainfall which increases toward the south.

77-86% is the average range annual air humidity in the basin having a minimum and maximum ranging from 64-76% and 92-97% respectively. From the south-eastern to the most northern part of the basin, the main annual potential evapotranspiration ranges from 1300mm to 1500mm respectively.

Meteorological data moreover exhibits depicted by reliably adverse temperatures amid the time with a despicable yearly hotness of around 26°C.

The hottest month (March) in the basin with an average monthly temperature of 27-29^{o} C. And mean temperature of the coolest month (August) ranges from 24-25^{o}C. 3-5^{o}C is the mean diurnal variety which is seen in the basin.

The effects of likely climatic changes on waterway releases (overflows) were dissected for the nation by Water Resources Commission (February 2000)). It is imperative that the effects and results referred to in that review report are appropriately perceived in future water assets arranging exercises for the Ankobra Basin. The fundamental discoveries of importance for the IWRM design are:

• There was a watched increment in temperatures of around 1°C over a 30-year time span, and diminishments in precipitation and spillover.[14]

2.3.5.2. *Availability of Surface water*

In general, the water (hydrological) adjust discourse to an entire year has been assessed in light of criteria got from the beforehand referred to WARM investigation and prior work by Opoku-Ankomah and Forson (Opoku-Ankomah, Y. also, M.A. Forson: [14]

Table 2.5 beneath gives an outline of the water adjust components. The outcomes depend to a huge degree on the evaluated rates, which decide the measure of the precipitation that winds up as surface water overflow and as groundwater energize. Once the river is a lasting stream, the aquifer base stream could be huge. Bring about a decline of net aquifer energize and a greater incentive for the assessed evapotranspiration.

Table 2.5: *Ankobra Basin Yearly water stability* [14]

Water Balance Component	Annual Amount	Rainfall In Percentage
Evapotranspiration-Actual	1,700 mm	
Rainwater	1,088 mm	
Ankobra Basin	8460km^2	
Volume Of Rainwater - Basin	14,540 million m^3	100%
Volume Of Evapotranspiration - Actual	9,300million m^3	63.96%
Groundwater Restore - Volume	2,890 million m^3	19.88%
Total Superficial Runoff - Basin	2,350 million m^3	16.16%

Table 2.6: *Despicable yearly capacity of the basin* [14]

River/Locality	Sub-Basin Area (Km^2)	Average Yearly Runoff (million m^3)
Bepo Sub-Basin	1,100	298
Ankobra at Dominase	8,125	2,208
Bonsaso Sub-Basin	1,250	325
Ankobra at Prestea	4,250	1,160
Ankobra at Ankwaso	680	183
Total Ankobra Basin	8,460	2,300

It must be accentuated, that this water adjusts introduction mirrors a much disentangled circumstance consolidating suspicions which can be refined, yet all things considered, is judged to give a sensible measure with regards to the relative size of the components of the bowl's hydrological cycle.

Overflow measurements

Recorded stream information and data on overflows are gotten from the Hydrological Services Department, which works various waterway checking stations in the Basin. It is noticed that the access information records contain all in all broken time arrangement with numerous holes throughout the years. Nonetheless, through the investigation of the stream records, irregularities are found to such a degree, to the point that the accessible stream records are to be viewed as questionable.

The stream administration of the Ankobra River shows a stamped changeability in the occasional spillover inside the year and additionally in the yearly streams. These highlights are featured in Table 2.7 for the occasional streams

***Table 2.7**: Despicable monthly flow of Ankobra River (2001-2007), Prestea (m^3/sec),* [14]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Average
Mean	2.2	3.5	4.3	8.5	23.8	27.8	21.4	11.6	19.3	35.6	19.2	5.5	15.2
Max.	2.9	16	10.8	12.4	52.1	57.8	35.3	27.2	43.3	65.7	54.9	7.9	32.2
Min.	1	0.6	1.05	5.2	2.6	8.8	10.4	3.9	3.5	8.2	3.2	1.7	4.2

2.4 EXISTING LEGAL FRAMEWORK

2.4.1. Permitting Atmosphere, Water Subdivision

Lawful and Governing Structure

Inside the general structure of the 1992 Constitutional structure, the strategy system for water assets administration and improvement in Ghana is attached on crucial reports:

Sole mandatory responsibility for water resource management as defined by WRC:

- control and deal with the nation's water assets, and
- Co-ordinate government strategies in connection with them

Likewise, IWRM attitude for water resource management in Ghana was clearly proposed by NWP and accentuates the emphasis on the succeeding values:

i. the lead of consultation the societal necessities a need, seeing money related estimation of water and the stock and ventures it gives;

ii. Preparatory rule tries to limit exercises which can possibly adversely influence the honesty of rivers;

iii. the standard of a specific end goal to guarantee participatory basic leadership at the most reduced fitting level in the public arena;

v. the rule of solidarity, communicating significant human friendship for normal issues identified with water;

vi. the rule that global collaboration is basic for the manageable advancement of communal basins;

vii. Standard of the best basic great to civilization in organizing clashing employments;

Different reports that supplement the WRC Act and the NWP are administrative instruments, controls and rules that address particular territories and issues of the whole water division. Some of the specific areas and issues and their relevant laws are:

- Ownership and Riparian Rights: it falls within the provisions of Article 269 of Ghana's Constitution, which tries to ensure water assets by setting up a Commission to institutionalize, oversee and fit Government approaches in connection to it. Water Abstraction, Diversion and Damming: This is under the Water Use Regulations 2001

(L.I. 1692) and what's more, gives strategies to apportioning licenses for different water utilizes including municipal, power generation, commercial, industrial, water transportation, agricultural, fisheries (aquaculture), domestic, recreational business, metropolitan, modern, rural, control age, water transportation, fisheries

- Quality standard provided by general society water utilities issued by the Ghana Standard Board (GSB [15]

2.4.2. International Agreements

Ghana is a cosigner to various universal laws, conventions, understandings, and revelations that place responsibilities on the administration in the supervision of water assets and the environment.

By a wide margin, the majority of the IWRM models in the NWP draw on the articles of the custom, going before the endorsing of the UN Convention on the Law of non-Navigational vocations of International Water Courses (May 1997)4 .[15]

2.5. SOME PREVIOUS WORK

From literature and international guidelines limits, due to ASGM, Bonsa River was observed to be affected by mercury (Hg) contaminants. The bioaccumulation of Hg over a drawn-out stretch of time in the verdure of the stream's biological system and in addition in people through the natural way of life can't be overlooked despite the fact that the grouping of Hg and arsenic (As) in sifted water was underneath WHO Guideline limits for drinking water. Valuation of buildup quality by means of the CSQC and effluence lists shows that it is passably influenced by As, manganese (Mn), and aluminium (Al) and vivaciously with Hg from the ASGM practices in the stream. It was exploratory that the surface water and dregs were more corrupted with Hg than revealed in two or three streams in most African and Asian Countries which have in addition been impacted by ASGM. The apportioning of perilous parts in the Bonsa conduit sections was free of $SO_4^{2-}$and aggregate natural carbon (TOC). [17]

It has been sober-minded that the buffering endeavour of carbonate is the reason for the moderately frail acridity saw in the waterway framework. The results achieved from the anthropological risk evaluation for As and Hg in the filtered water from the stream prescribe that Hg is the enormous toxins in the conduit. Amphibian life and the social populace that relies

upon this water framework for their day by day exercises are at the most noteworthy hazard because of the presence of Hg. Fluctuating from other stream water-related examinations in Ghana, this examination contributes the dedication of point source toxins to water quality status. [17]

2.6. GAPS IDENTIFIED

There are several gaps which can be adopted for the Ankobra river basin development:

1. The Ankobra river basin where small-scale gold mining activities are practised, there is a low level of reclamation activities.
2. For the modern elementary technique of prospecting bookkeeping, many small-scale miners do not have any acquaintance. Thus mining continues to be done as a gamble that someone luck is going to strike.
3. Drinking water quality utilities of the basin pose problems because of the presence of hazardous chemicals and hence needs a more integrated approached.

2.7. OBJECTIVES OF THE STUDY

For advancement plans for revitalization and development, following objectives need to be considered and achieved with the help of tools and techniques available.

The followings are the major objectives of the thesis.

1. To develop support assessments for watershed land-use change, pollutant discharges, and management practices on water quality.

2. To promote environmentally friendly mining techniques with automation and Integration to advanced technologies in the small-scale gold mining as well as, it's mitigating impacts and reclaiming the land through scientifically developed mine closure plans.

3. To harness green electricity from the perennial stream and biogenic forest produce to phase-out thermal power.

4. The public infrastructure program to augment the reclamation, redevelopment and revitalization of the area is the advancement plans for river revitalization.
5. Advanced plans of developing green space, better ecological flow and other suitable measures.

CHAPTER-3

METHODOLOGY, DATA COLLECTION AND PROCESSING

3.1 Methods of Data collection

To accomplish this phase comprehensive Ankobra river basin advancement revitalization plan, the following activities were achieved through different approaches

Within this activity the documentation was made from numerous sources of information;

1. Scientific literature – books, articles and other scientific publications
2. Official website of Ghana Water Commission on Ankobra river basin and international
3. Transcribed news coverage from television, radio interviews, newspaper publications and websites of the municipality
4. Downloading of three satellite images covering the period 1986 to 2016.
5. Questionnaires on main and sub-indicators based on average weight for revitalization and development of the Ankobra river basin.

3.1.1. Data Acquisition

From the United States Geological Survey (USGS) and the Global Land Cover Facility (GLCF), three satellite images cover the era of 1986 to 2016 were attained.

On the record of heterogeneity of land utilize, soil qualities, lithology, topography, and stream system distribution. The combination of geology and available spatial data of soil in the geographical information system (GIS) were overlaid to enhance each delineated sub-basin. (Table 3.1 & 3.2, 3.3, 3.4). LULC data was attained by image classification of a Landsat 8 OLI/TIRS under collection 1 Level 1 and 7 ETM+ C1 Level- 1 taken on 29th December 2015 – 5th January 2016 and 6th – 15th January 2002 respectively and downloaded free from the USGS website. Also from Landsat 1-5 multispectral scanner, images taken from 18th – 27th January 1986 under Global Land Cover Facility (GLCF).

Table 3.1. *Coordinates of the study area*

Coordinates	2° 48′ 42.588″ **W**	1° 41′ 36.54″ **W**	1° 30′ 28.388″ **W**	2° 41′ 17.153″ **W**
	6° 30′ 29.579″ **N**	6° 31′ 38.108″ **N**	4° 49′ 59.073″ **N**	4° 52′ 50.394″ **N**

Table 3.2.*Path/row number and its acquisition date for the year 1986 – 1996 of the study area*

Sensor	**Number of bands**	**Path/row orbit/frame**	**Number of scenes**	**Spatial resolution (m)**	**Acquisition date**	**Source**
Landsat 1-5 Multispectral Scanner	4	194/56	2	30, 30	18/01/1986	**GLCF**
		194//57	2	30, 30	27/01/1986	
		195/56	2	30, 30	27/01/1986	

Table 3.3. *Path/row number and its acquisition date for the year 1996 – 2006 of the study area*

Sensor	**Number of bands**	**Path/row orbit/frame**	**Number of scenes**	**Spatial resolution (m)**	**Acquisition date**	**Source**
Landsat 7 ETM+ C1 Level-1	7, 8	194/56	2	30, 30	15/01/2002	**USGS**
		194//57	2	30, 30	15/01/2002	
		195/56	2	30, 30	06/01/2002	

Table 3.4. *Path/row number and its acquisition date for the year 2006 – 2016 of the study area*

Sensor	**Number of bands**	**Path/row orbit/frame**	**Number of scenes**	**Spatial resolution (m)**	**Acquisition date**	**Source**
Landsat 8 OLI/TIRS C1 Level-1	7, 8	194/56	2	30, 30	29/12/2015	**USGS**
		194//57	2	30, 30	29/12/2015	
		195/56	2	30, 30	05/01/2016	

3.2 Delimitation of Basin Using ASTER Digital Elevation Model (DEM)

3.2.1 Aerial Imagery and Scanned Maps

Shapefiles were prepared for a 30m resolution ASTER digital elevation model (DEM) of the study area by downloaded free watershed from the USGS site for the outline of the basin into watersheds DEMs handling connected ARC hydro-methods as depicted by the centre for research in water resources (2007/2008). Aerial photos taken from google helped to make a quick visual assessment of the study area in respect of the type of land use and land cover distribution. Elevated information is critical in light of the fact that it gives fundamental data on the kind of land use and land cover for a territory of intrigue.

3.3 LULC Analysis (Landsat Enhanced Thematic Mapper (ETM+) Imagery of 2017

Land use/land cover changes happen by the modification of the regular scene through both anthropogenic activities and characteristic procedures[18].

Common causes incorporate volcanoes, storm surges, surges, dry spells, seismic tremors and out of control fires, while anthropogenic landuse/land cover changes are impacted for the most part by financial drivers, for example, populace development, rustic urban movement, migration, urbanization, government arrangement and monetary improvement [18].

The path toward arranging contrasts in the state of the land cover by mapping it at different conditions above an era is known as Land use/land cover change revelation [18]. Analysis of satellite images to recognize arrive utilize/arrive cover changes relies upon the conjecture that the noted electromagnetic radioactivity, which is the preface of requesting land covers, is adjusted as the land use/land cover of the similar geographical region [18][19][20].

Post-classification comparison, spectral-temporal, multi-data classification combined analysis and unsupervised change detection were the consisting classification methods. [18]

3.3.1. Pre-Processing of Image

Blunders in mapping land use/land cover deviations can be decreased by execution image pre-processing before order and change recognition strategies are connected.

Radiometric and geometric corrections are the two main types of image pre-processing [18]. The contortions coming about because of sensor and stage mistakes, and also the revolution of the Earth in connection to the sensor, is redressed by image enlistment. Geometric redress changes over the satellite image geometry to true arrange and projection frameworks [18] [21], the target of radiometric revision in change discovery is to guarantee that accessible images are thought about based on comparable radiometric properties [18]. Images pre-preparing in this investigation comprised of just geometric adjustment. Every one of the images had been geo-referenced to the UTM WGS84 Zone 30 North projection by the information providers, yet they didn't coordinate with the geo-referenced topographic territory. Beginning geometrical images were amended after which the rest were co-enlisted to them by the high-determination. Murkiness expulsion was not executed, on the grounds that accessible calculations contorted the images and diminished their quality. In any case, the dimness was not viewed as tricky since the change identification method embraced was a post-order examination, which depends on characterized singular images.

3.3.2. Classification and Accuracy Assessment

Image classification was directed by producing unearthly marks, utilizing preparing tests made for each satellite images. The preparation tests were made by arbitrarily choosing 70% of the example class information for each satellite image. Five topical classes were chosen to speak to the land front of the Ankobra Basin, utilizing the USGS's territory cover order conspire for Landsat information [18] [22]. The classes utilized are water, evergreen timberlands, settlements, bushes/homesteads and mining regions (Table 3.5). Subsequent to making the otherworldly marks, the distinguishableness of the topical classes was checked utilizing the Jefferies-Matusita's networks [18].

In multidimensional perceptions, numerous characterization calculations (unsupervised) require the choice of ideal groups in which the classes are generally unmistakable. The Jeffries–Matusita (JM) separate is generally utilized as a distinguishableness standard for ideal band choice and assessment of characterization comes about lastly, the MLC calculation was utilized to all the images using the generated spectral signatures.

Table 3.5. *Land Cover Image Classifications*

Land cover	Description	Photo
Dark Forest	It includes African mahogany, walnut, bamboos, Afrormosia etc. and species such duiker, bongo baboons.	
Built-Up	It comprises of playing grounds, industrial and residential structures, and road infrastructures etc.	
Agriculture/Farmland	Tree crops, cereals, vegetables, cash crop and exposed land etc.	
Mining area/Bare land	It includes all areas of land where mining activities are practiced and after mining lands etc.	
Water body	It includes pools, wetland or more rarely puddles, rivers and streams	

3.3.3. Change Detection

The land cover maps for 1986, 2002 and 2016 created after picture characterization were renamed and consolidated to shape various bi-worldly land cover change maps for the periods 1986-1996, 1996-2006 and 2006 - 2016 utilizing Erdas and GIS spatial investigation. The regions and extents of progress starting with one topical class then onto the next (change lattice) between the periods and the yearly rates of the progressions, were figured to clear up the sizes and direction of the land cover headway for the three eras.

At long last, the general deforestation rates were resolved, by blending evergreen and auxiliary woodland classes in every period and figuring the extent of changes every year, between the three-time frames, utilizing the Food and Agricultural Organization's (FAO) meaning of timberlands (FAO, 2010) [18]. The change identification in this examination depends on the hypothesis that land cover classes in the vicinity of 1986 and 2016 continued as before.

3.3.4. Questionnaires

For authenticating the data for the study, a designed questionnaire was distributed at randomly to the selected non-governmental organization and government agencies for 100 individuals.

Main indicators such as mining, navigation, agriculture, hydropower, biological degradation, urbanization and infrastructure development, natural causes and water quality, as well as other sub-indicators were subject to a scale of 1 – 10 (minimum - maximum).

3.4 WATER QUALITY DATA

3.4.1 Chemical Composition in Ankobra Basin between May and June 2013

The concentrated basic focus in the separated superficial water and mass low dregs of the Bonsa waterway framework contrasted and chose rule esteems and world normal foundation levels, are concise in Tables 3.6 and 3.7. The centralization of Cu in both the store and sifted surface water was underneath as far as possible (0.01 mgL^{-1}). [17]

All in all, the mean grouping of components in dregs was greater than in waterway water. The Al fixation in the dregs expanded directly from SL1 (6240 mg kg^{-1}) to SL4 (18905 mg kg^{-1}) and SL5 (1140 mg kg^{-1}) to SL6 (9118 mg kg^{-1}) with the most reduced happening at SL5. The convergence of Mn expanded consistently from SL1 (176 mg kg^{-1}) to SL6 (804 mg kg^{-1}). The convergence of Hg is generally uniform at test areas of SL1 (1.2 mg kg^{-1}) to SL6 (1.14 mg kg^{-1}). The centralization of As is generally uniform from SL1 (0.56 mg kg^{-1}) to SL3 (0.34 mg kg^{-1}) and after that expanded to SL6 (1.06 mg kg^{-1}). By looking at the mean convergence of harmful components in the dregs to Canadian Soil Quality Guidelines for the assurance of amphibians (Tables 3.6 and 3.7), we watch that the intensities of As and Cu are not as much as the relating Threshold Effect Concentrations (TECs) and Probable Effect Concentrations

(PECs). The TECs valves surpassed the residue concentration of Mn but was a lesser amount of PECs.[17]

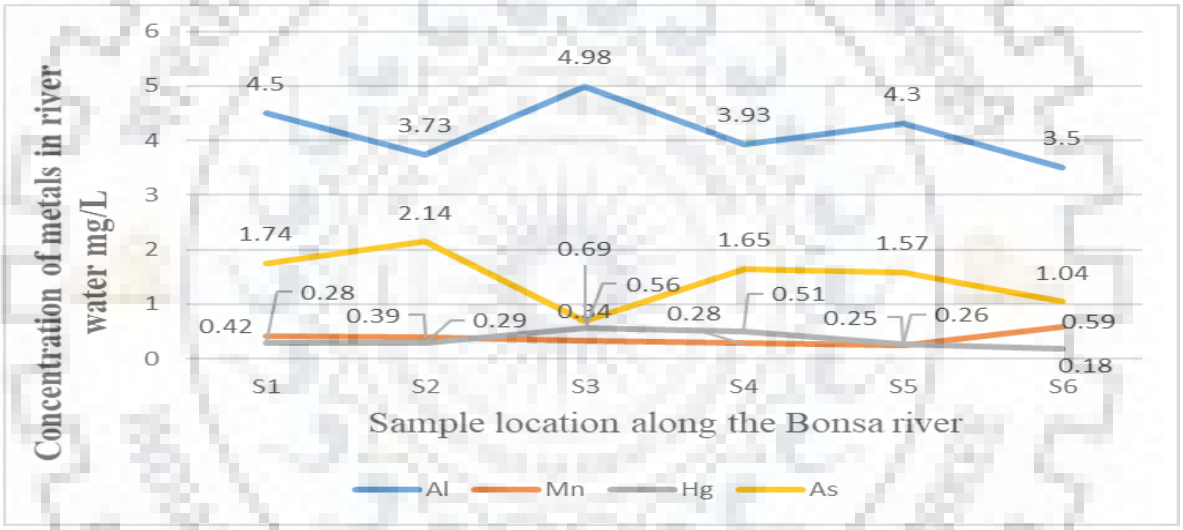
Table 3.6 :*Residue element concentration in the river* [17]

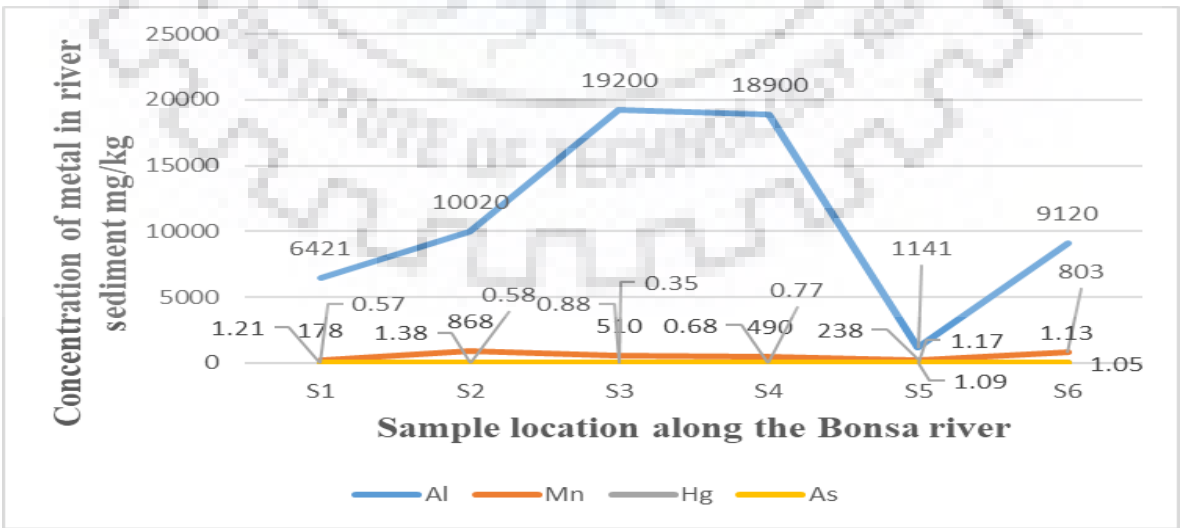
Sample location along the river	**Sediment (bulk)**							**Surface water (filtered)**					
	SO_4^{2-}	TOC	Al	Mn	Cu	Hg	As	SO_4^{2-}	Al	Mn	Cu	Hg	As
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
SL1	314	846	6420	176	<0.01	1.2	0.56	13.3	4.4	0.41	<0.01	0.29	1.72
SL2	302	574	10023	867	<0.01	1.36	0.59	12	3.75	0.38	<0.01	0.28	2.13
SL3	274	725	19205	508	<0.01	0.86	0.34	11.1	4.99	0.36	<0.01	0.58	0.7
SL4	231	425	18905	492	<0.01	0.66	0.79	43.3	3.95	0.29	<0.01	0.5	1.64
SL5	702	966	1140	237	<0.01	1.15	1.07	66	4.4	0.28	<0.01	0.27	1.58
SL6	146	835	1918	804	<0.01	1.14	1.06	74.5	3.9	0.58	<0.01	0.19	1.03
Mean	328	729	9602	514	<0.01	1.06	0.74	36.7	4.23	0.38	<0.01	0.35	1.47
Max	702	966	19205	867	<0.01	1.36	1.06	74.5	4.99	0.58	<0.01	0.58	2.13
Min	146	425	1140	176	<0.01	0.66	0.34	11.1	3.75	0.28	<0.01	0.19	0.7
Average shale values	-	-	80000	850	-	0.0004	0.013	-	-	-	-	-	-
WHO	-	-	-	-	-	-	-	400	0.1	0.5	2.0	6.0	10.0

Table 3.7. Fortification for *aquatic life on sediment quality procedures* [17]

Al	Mn	Cu	Hg	As	References
TECs					
LEL	459	17	0.19	5.99	Persaud et al. 1992
ERL	_	33	0.4	8.1	Long et al. 1995
TEL	_	35.6	0.16	5.8	Smith et al. 1996
MET	_	27.9	0.19	6.99	EC and MENVIQ 1992
PECs					
SEL	1101	111	1.99	32.9	Persaud et al. 1992
ERM	_	271	1.29	69.9	Long et al. 1995
PEL	_	196.9	0.48	16.9	Smith et al. 1996
TET		85.9	1.9	16.9	EC and MENVIQ 1992

(a) Sample distances in km





(b) Sample distances in km

Figures. 3.1. *River water, metal concentration variation (a), river sediment (b) against Bonsa river sample location. The direction of river flow: SL1 to SL6*[17]

The Bonsa River was seen to be influenced by Hg contaminants from ASGM when appeared differently in relation to composing regards and all-inclusive run limits. Notwithstanding the way that the centralization of Hg and As in isolated water was underneath WHO Guideline limits for drinking water, the bioaccumulation of Hg over an extended time allotment in the greenery of the conduit biological system and in addition in people through the natural pecking order can't be disregarded. It was seen that the surface water and silt were more corrupted with Hg than point by point in a few conductors in Ghana, Zimbabwe, Tanzania, Suriname, Brazil, Thailand, China, Kenya, Indonesia, Guyana, and Philippines which have moreover been affected by ASGM. The allotting of deadly segments in the Bonsa conduit compartments was free of SO_4^{2-} and TOC [17].

The generally feeble corrosiveness saw in the bowl was likely because of the buffering activity of carbonate. The outcomes got from the human hazard evaluation for As and Hg in the separated water from the stream recommend that Hg is the most basic contamination in the waterway. Oceanic life and the human populace that relies upon this water framework for their day by day exercises are at the most astounding danger because of the presence of Hg. This investigation looks at the commitment of guide premise toxins toward water quality status and incorporates out of the blue human wellbeing hazard valuation to stream water quality, particularly from other waterway water-related examinations in Ghana.[17]

3.4.2. Water Quality and Pollution

Water contamination has been perceived as the main water administration issues in the basin (WRC, 2000)[14]. This is expected basically to the transfer of natural mining effluents from areas, for example, Tarkwa, Beposo, Prestea, Nsuta and Awaso. Presenting to the Mining Sector Support Program (MSSP) Report11, the real wellspring of arsenic is by all accounts along the Ankobra River from Prestea downstream to Dominase. The report demonstrates that the amount of arsenic transported by the stream in 2006 was 18,000 kg/year. In this way, the principle errand in the Ankobra River Basin is the impact of mining exercises on the nature of the shallow water of the basin. [14]

3.4.3. Surface Water Quality

The outcomes from the WRC ponder have recommended the accompanying pattern of particle strength in these waters: Na>Ca>Mg>K and HCO3>SO4>Cl which in this way affirms the significance of Na and HCO3. A large portion of the significantly follow metals was beneath recognition limits with the special case, at times, of Fe, Mn, and Zn. Add up to suspended solids went in the vicinity of 10 and 120mg/l as it were. High Hg levels were distinguished in streams where dynamic unlawful mining is serious. Arsenic focuses were additionally high in these streams. Dregs tests, by and large, displayed high estimations of As and Fe. The expanded exercises in surface mining combined with the absence of sufficient land utilize perform in the bowl have prompted the quickened disintegration of topsoil and subsequently sloppy of the water. The pattern, in this way, is towards expanded turbidity [14]

The human exercises have affected extraordinarily on the environment and decent variety of surviving sorts in the bowl. A portion of the protected regions has been lost to unlawful cutting tool tasks and from the vast scale surface mining exercises. The high rate of timber logging, and in addition fuelwood extraction, has additionally exacerbated deforestation and, subsequently, the powerlessness of the surface water asset. [14]

3.4.4 Sources of Pollution and Sanitary Condition

The debasement of the water nature of River Ankobra as shown in Section 3.4.2 represents a succession of dangers. The expanded turbidity, arsenic loads from old mine dumps and the introduction of arsenic-bearing rocks from the exercises of the mining activities and also coincidental spillages from the mines are a risk to the idea of the surface water and furthermore the groundwater resources

If not observed, the substantial scale mining tasks and developing number of unlawful mining exercises inside the bowl have the capability of expanding suspended solids of the waterway, and thusly the turbidity of the water. Likewise as showed before these exercises keep an eye on upsurge the arsenic stacking of the stream. Moreover, the expanding utilization of the stream for the evacuation of both strong and fluid waste by the riparian groups additionally represents a risk to the water quality. The repercussions of the above to the water assets in the bowl are:

• Dwindling accessibility of value water for compact utilize;

• High water treatment cost;

• High infection predominance and unintentional passing's resultant from metallic harming and related high therapeutic expenses;

• Loss of biodiversity; and

• Water utilizes clashes. [14]

3.4.5 Sanitary Situation

For the most part, the sterile and abundance transfer benefits over the bowl are lacking prompting the transfer of local sewage and junk into the waterway framework. CWSA is giving KVIPs to families in different groups to enhance sanitation.

The Basin is for the most part appropriate for tree trim manors, particularly cocoa. The greater part of the cocoa ranches are youthful so little compost is utilized on the homesteads by and by. In any case, when ranches get more established, agriculturists turn to enhanced agronomic practices, and consequently, the utilization of composts and agro-chemicals would without a doubt be more pervasive to rising yields. The outcome is that overflows from ranches coming to waterway streams would expand eutrophication of the surface waters and contamination with natural poisons. [14]

3.4.6. Patterns in Pollution Load

In advance of facilitating urbanization and industrialization, combined with an upsurge in water supply scope in the bowl, the conceivable contamination load and its effect on the water quality will without a doubt augment interestingly.

Arsenic harming of surface waters and contamination of groundwater with Hg is conceivable to increment with the deluge of individuals into the bowl honing "galamsey" exercises. Arsenic is consistently existent in the mineral zone.

Phosphate levels are somewhat more articulated and no more upstream reach at Ankwaso and furthermore at Dominase, the most downstream of the water quality checking focuses. Their closeness to urban focuses would recommend some impact from these sources and this has suggestions for the creation of consumable water.

The chief wellspring of arsenic and suspended solids is by all accounts along the Ankobra River from Prestea down to Dominase, and this is probably going to increment with the expansion of

the tasks of the vast scale mines and in addition the exercises of both little scale and illicit mining activities.

Without a doubt, the foundation of wastewater treatment conspires on a more extensive scale will be required in parallel with advance change and augmentation of the water supply framework. [14]

CHAPTER-4

RESULTS, DISCUSSIONS AND PROPOSED ADVANCED PLANS

4.1. CHANGE DETECTION

From the gathered data sets, information obtained, literature studied and earlier works in the field, the present position of Ankobra Basin is illustrated hereunder for leading to purposeful advanced plans to revitalize the river stream.

The generation of image classifications for 1986 - 1996, 1996 - 2006 and 2006 - 2016 can be found in figures 4.1, 4.2 and 4.3, the land use/ land cover matrices are shown in tables 4.1, 4.2 and 4.3. While the proportions of land cover are shown in table 4.4.

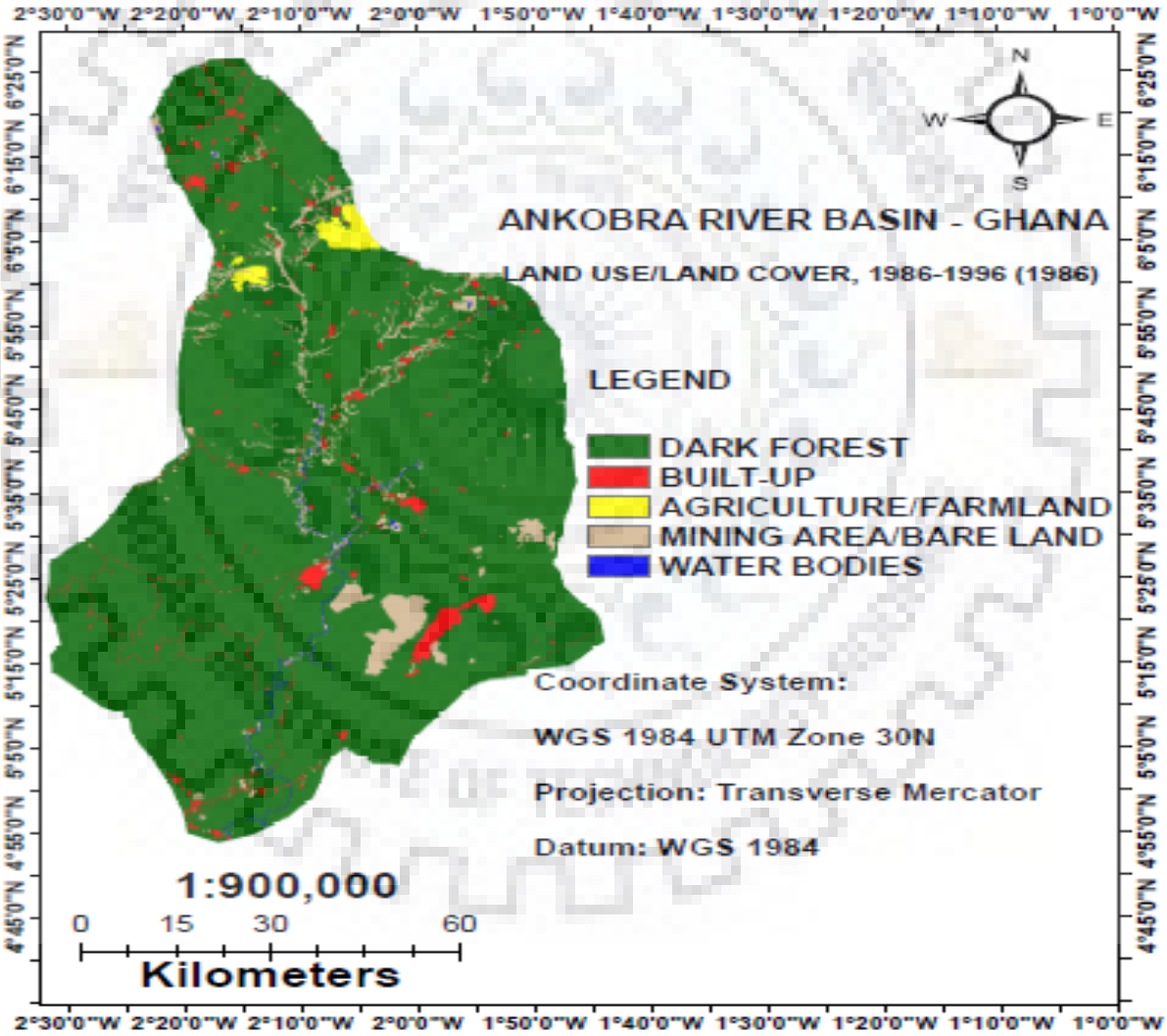


***Figure 4.1**: 1986-1996 (1986) land use land cover*

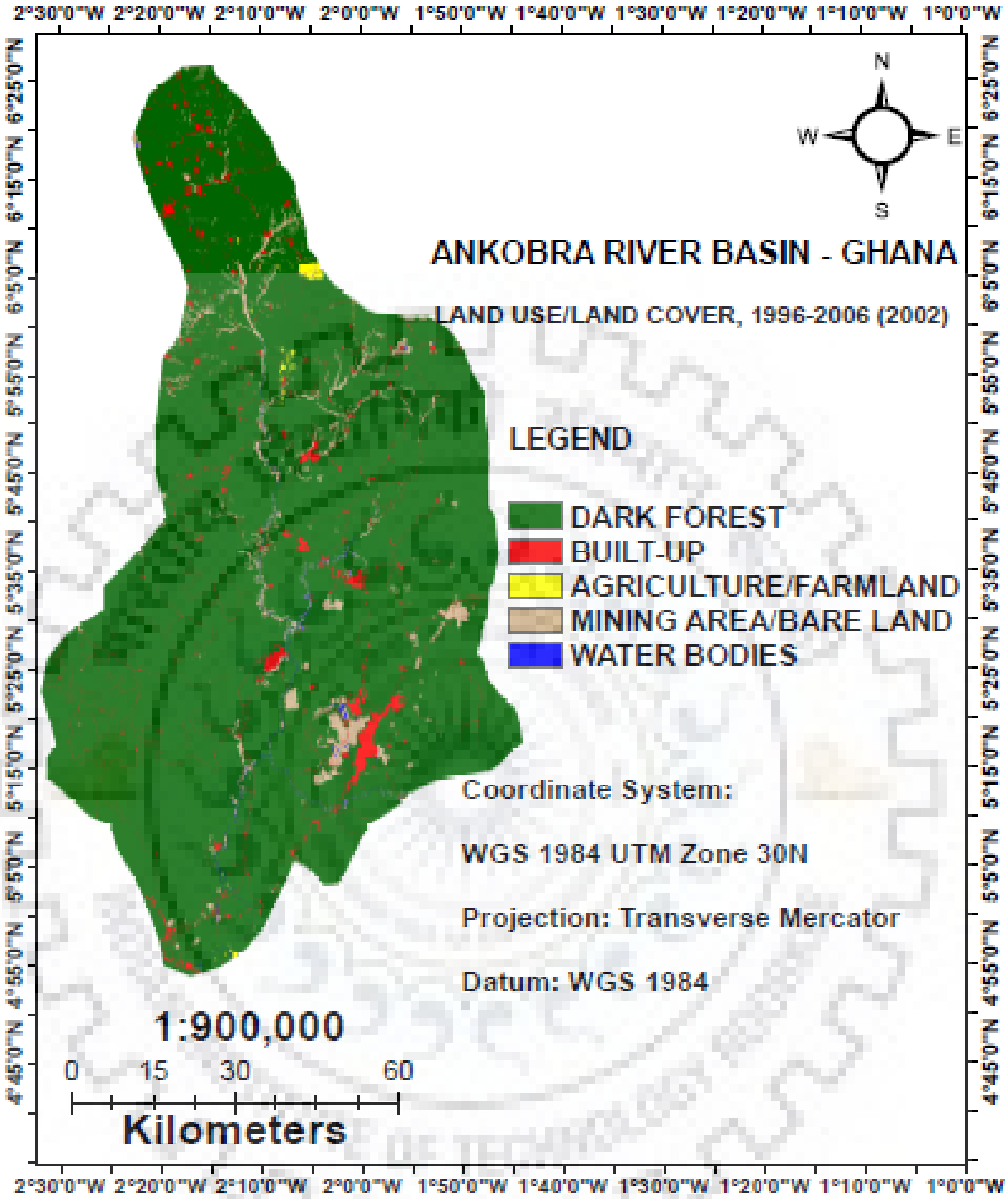


***Figure 4.2**: 1996-2006 (2002) land use land cover*

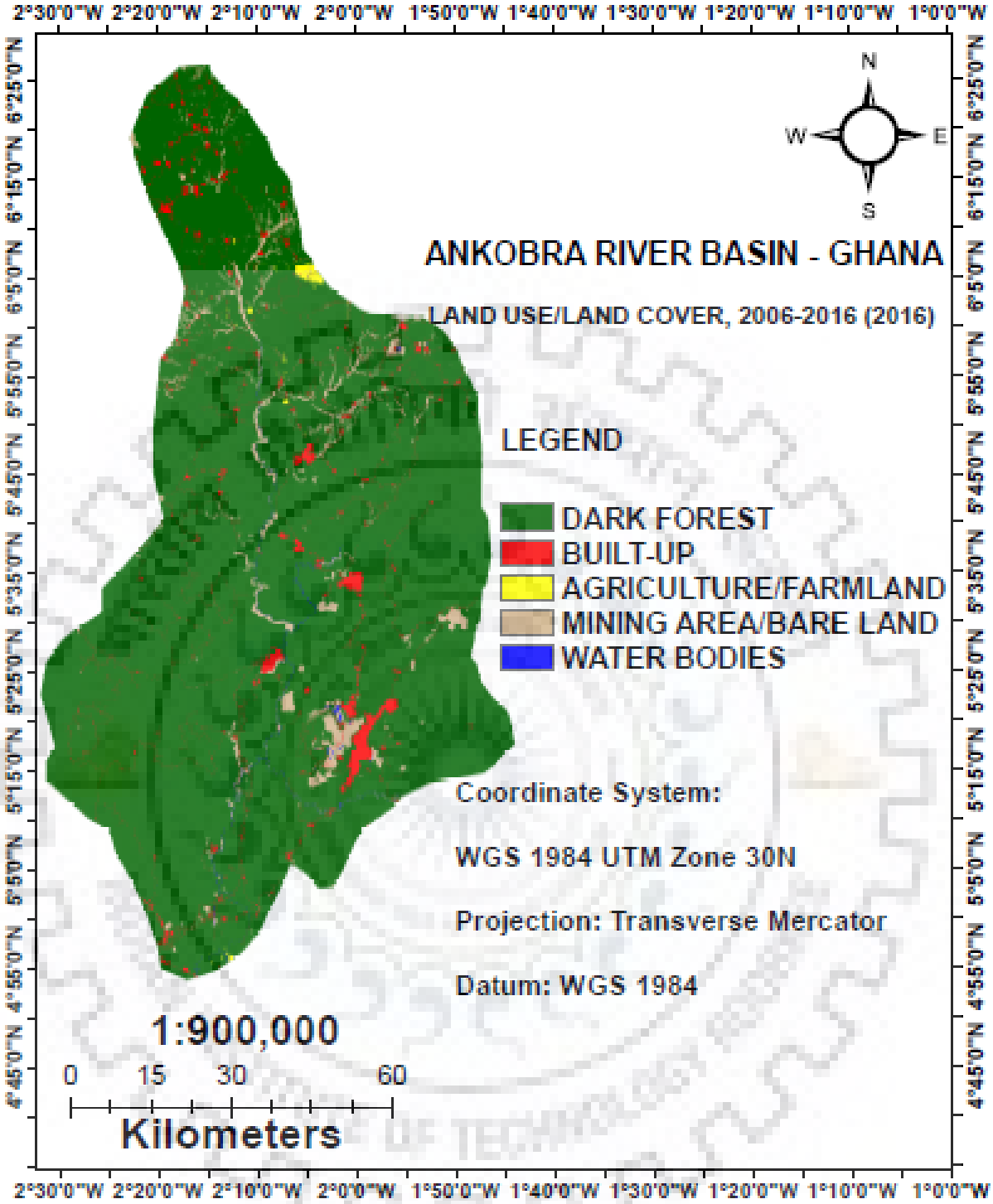


***Figure 4.3**: Land use land cover for 2006-2016 (2016)*

*Table 4.1: Land use change matrix 1986-2006 (km^2) ** from 1986, * to 2006*

LAND USE/LAND COVER CHANGE MATRICES							
	FROM 1986						
	LAND COVER	DARK FOREST	BUILT-UP	AGRICULTURE / FARMLAND	MINING / BARELAND	WATER BODIES	TOTAL KM² *
IN 2006	DARK FOREST	7780.99	6.40	0.00	11.62	1.75	7800.75
	BUILT-UP	60.84	185.25	0.00	1.60	0.13	247.82
	AGRICULTURE / FARMLAND	6.97	0.00	9.78	0.00	0.00	16.75
	MINING / BARELAND	79.49	1.37	0.00	184.61	0.21	265.68
	WATER BODIES	3.34	0.13	0.00	0.17	15.91	19.55
	TOTAL KM²**	7931.63	193.15	9.78	198.00	18.00	8350.56

*Table 4.2: Land use change matrix 2006 – 2016 (km^2) ** from 2006, * to 2016*

LAND USE/LAND COVER CHANGE MATRICES							
	FROM 2006						
	LAND COVER	DARK FOREST	BUILT-UP	AGRICULTURE / FARMLAND	MINING / BARELAND	WATER BODIES	TOTAL KM² *
IN 2016	DARK FOREST	7647.17	39.94	1.91	42.74	1.66	7733.41
	BUILT-UP	71.10	204.93	0.01	4.98	0.08	281.10
	AGRICULTURE / FARMLAND	7.92	0.03	14.83	0.00	0.00	22.78
	MINING / BARELAND	68.84	2.59	0.00	216.18	1.31	288.92
	WATER BODIES	5.72	0.34	0.00	1.78	16.51	24.35
	TOTAL KM² **	7800.75	247.82	16.75	265.68	19.55	8350.56

*Table 4.3: Land use change matrix 1986-2016 (km^2) **from 1986, *to 2016*

LAND USE/LAND COVER CHANGE MATRICES							
	FROM 1986						
	LAND COVER	DARK FOREST	BUILT -UP	AGRICULTURE / FARMLAND	MINING / BARELAND	WATER BODIES	TOTAL KM² *
IN 2016	DARK FOREST	7707.62	7.58	0.04	16.52	1.65	7733.41
	BUILT-UP	93.72	184.63	0.00	2.68	0.07	281.10
	AGRICULTURE / FARMLAND	13.04	0.00	9.73	0.00	0.00	22.78
	MINING / BARELAND	109.87	0.63	0.00	178.12	0.30	288.92
	WATER BODIES	7.38	0.31	0.00	0.67	15.99	24.35
	TOTAL KM² **	7931.63	193.15	9.78	198.00	18.00	8350.56

Table 4.4: The percentage of land cover between 1986 and 2016

PROPORTION OF LAND COVER BETWEEN 1986 - 2016							
	1986		2006		2016		
LAND COMPOSITION	SPACE KM²	%	SPACE KM²	%	SPACE KM²	%	% INCREASED
DARK FOREST	7931.63	94.98	7800.75	93.42	7733.4	92.61	-2.37
BUILT-UP	193.15	2.31	247.82	2.97	281.1	3.37	1.05
AGRICULTURE / FARMLAND	9.78	0.12	16.75	0.20	22.78	0.27	0.16
MINING / BARELAND	198	2.37	265.68	3.18	288.92	3.46	1.09
WATER BODIES	18	0.22	19.55	0.23	24.35	0.29	0.08
TOTAL	8350.6	100	8350.6	100	8350.6	100	

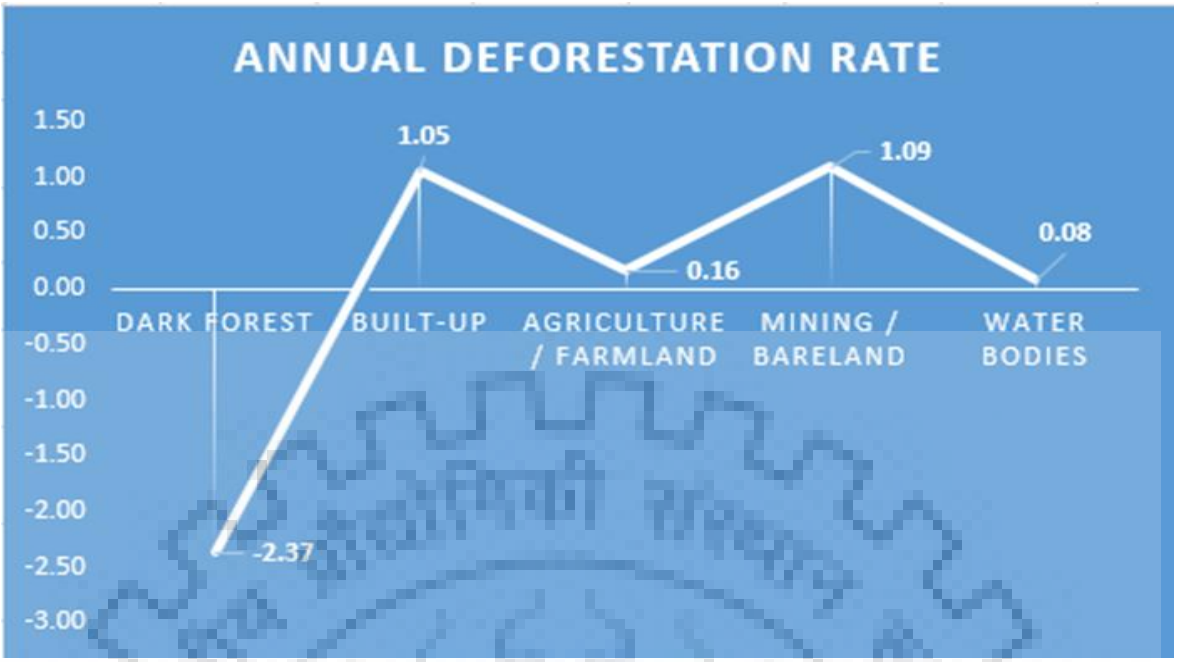


***Figure 4.4**: Annual deforestation rate*

Table 4.5: Land cover in relation to years between 1986 and 2016

LAND COVER						
YEARS	**DARK FOREST km²**	**BUILT-UP km²**	**AGRICULTURE / FARMLAND km²**	**MINING / BARELAND km²**	**WATER BODIES km²**	
1986	7931.63	193.15	9.78	198	18	
2006	7800.75	247.82	16.75	265.68	19.55	
2016	7733.41	281.1	22.78	288.92	24.35	

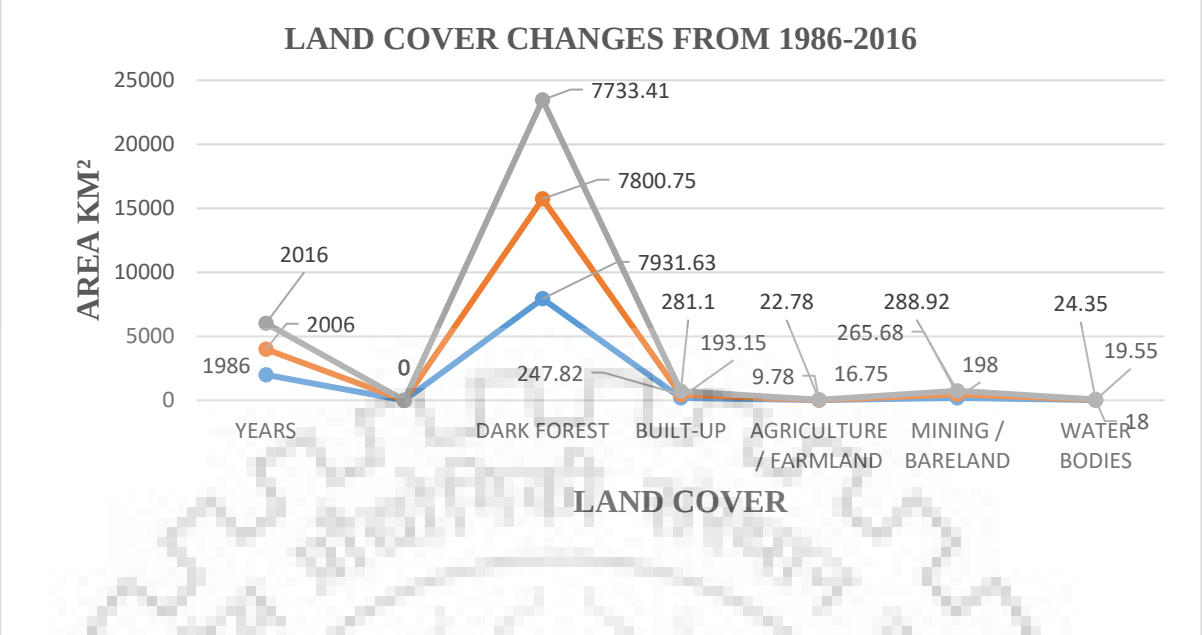


***Figure 4.5**: land cover with respect to years between 1986 and 2016, area in km²*

The Ankobra river basin is covered by five main classes: dark forest, built - up, agriculture/farmland, mining areas/bare land and water bodies. The total coverage area of dark forest have been decrease between 1986 and 2016, while mining areas/bare land and built-up have augmented substantively. Dark forest, prevailing the land cover, employed 94.98% of the basin area in 1986, abridged to 93.42% in 2006, declined considerably within 2006 and 2016 (92.61%). The area under built-up increased from 2.31% in 1986 to 2.97% in 2006, and further increased again to 3.37% in 2016 (Table 4.4). For the agriculture/farmland class, the area increased minimally between 1986 and 2016. Mining areas / bare land increased consistently from 2.37% (198 km^2) in 1986 to 3.18% (265.68km^2) in 2006 and further increased again in 2016 by 3.46% (288.92 km^2), while water bodies remained almost the same but rather polluted by mining activities along the basin. (Table 4.4).

The change grid shows the adjustment in extents of land cover from the previous year to the most recent year. The diagonal components in the change framework demonstrate regions of no change, while the off-diagonals indicate changes from one class to the next. In this manner, the whole of the transverse components exemplifies the aggregate territory of land cover have no change. The annualized rate of progress demonstrates the level of progress in the land cover zone between the periods (that is the difference between the final and the initial year, table 4.4. Figure 4.4 illustrates annual deforestation rate for the various classes from 1986 to 2016, -

2.37% (decreased in dark forest), 1.05% increase of built-up, 0.16% in agriculture/ farmland, 1.09% in mining / bare land and no change in water bodies.

The consequences of the examination demonstrate that deforestation in the Ankobra River bowl is across the board, affirming the past land cover consider by Kusimi (2008). The present investigation demonstrates that in the vicinity of 1986 and 2016, dark forest have been lessened by 2.37%, while mining zones expanded 1.09% and settlements 1.05% (figure 4.4).

The outcomes additionally demonstrate that, in spite of the fact that the deforestation rate has been expanding with time, over half of the land cover in the Ankobra River basin stayed unaltered in the vicinity of 1986 and 2016. Dark forest has the biggest stable class (94.23% in the vicinity of 1986 and 2006, 92.61% in the vicinity of 2006 and 2016), while agribusiness/farmland were the most divided classes (Table 4.4). The recorded land cover changes show that a few regions which were initially secured by dark forest or horticulture/farmland have been changed over to other cover composes, and the recovery of the first vegetation (reforestation) amid the three-time frames is little, contrasted with the general deforestation.

4.2. Questionnaires

Among the respondents were researchers, engineers, water quality experts, laboratory managers, environmentalist, hydrologist, directors, hydrogeologist, commissioners, and policy analysts.

Out of the 100 distributed questionnaires, a total of 80 completed questionnaires were returned and then analyzed statistically.

This procedure was pertinent for items having scale of minimum to maximum (1 - 10) where the respondents were inculcated to provide their peculiar opinion or perception on the scale. Thus major indicators (mining, navigation, agriculture, hydropower, biological degradation, urbanization and infrastructure development, natural causes and water quality) and sub-individual items were given equal weight by;

- Finding the weight for each main indicators
- Finding average weight for each main indicators

Thus indices of main indicator (IMI)

=indices of sub indicator under main indicator (ISI) X weight average of main indicator (WAI)

For sub indicators – attributes

- Percentages for each distinct sub-indicator were calculated i.e. (weight/total)*100
- Average percentages of each individual sub indicators

Thus total index = sum of average indices of main indicators.

The outcomes show that the main indicators of 0.344 is very poor and needs urgent attention to revitalized and develop the river basin.

See appendices 8 – 48 below.

Table 4.6*: weight index of main indicators for revitalization and development of Ankobra river basin*

MAIN INDICATORS	AVERAGE INDICES	PERCENTAGE INDICES	TOTAL INDEX
Mining (illegal)	0.040	4.0	
Navigation	0.042	4.2	
Agriculture	0.036	3.6	
Hydropower	0.053	5.3	
Biological degradation	0.038	3.8	**0.344**
Urbanization and infrastructure development	0.054	5.4	
Natural causes	0.043	4.3	
Water quality	0.038	3.8	

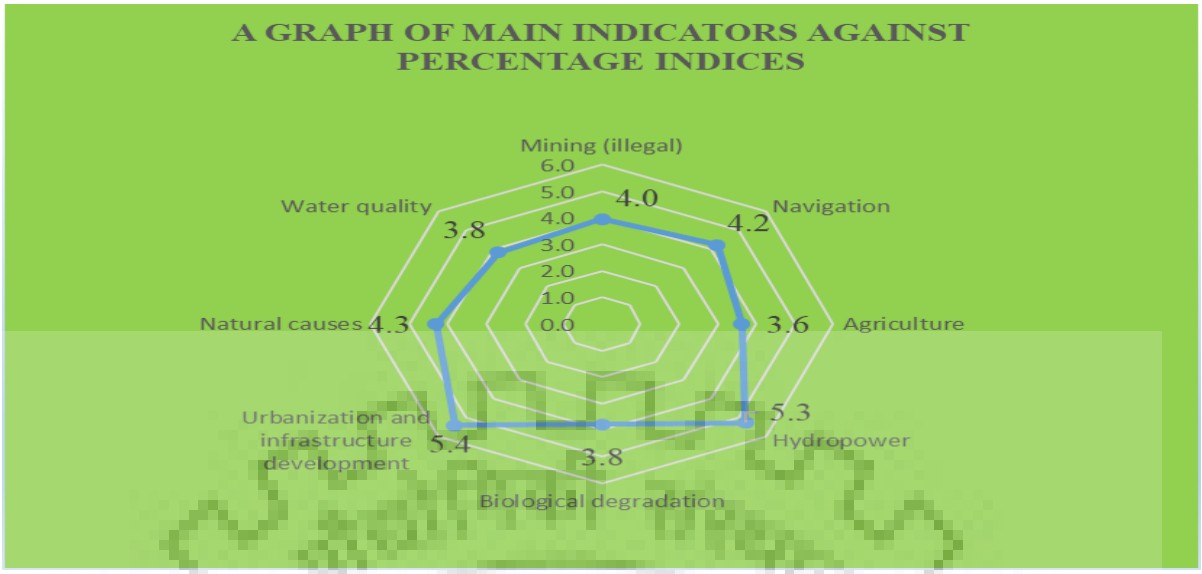


***Figure 4.6**: Graph of main indicators against percentage indices*

4.3. ADVANCED PLANS DISCUSSION, SUITABILITY AND OUTCOME

4.3.1. Riparian Buffer Zones (RBZS)

The seepage zone circumscribing the stream is known as the riparian zone and is of basic significance to the capacity, and in addition the assurance and supervision of a river [23]. The riparian zone has vibrant environments categorized by strong energy regimes, considerable habitat heterogeneity, a diversity of ecological procedures and multidimensional gradients. Riparian buffer zone (RBZ) is a territory of trees, generally joined by vegetation and other vegetation's along a stream, basin area that is figured out how to keep up the unwavering superiority of the conduit to lessen contamination and to give nourishment, living space and warm security for fish and untamed life. The unique ecological occupations of riparian zones are interconnected to dynamic biophysical processes and interactions crossways multiple spatial and progressive scales. Riparian buffer zones help in controlling soil or dregs disintegration, keeping up water quality, give environments to various amphibian life forms, flooding and temperature control and develop a steady waterway basin bank.

Human interference was recorded more than agricultural activities because of illegal mining processes on both banks of the study area. Although riparian zones exist along the Ankobra River, it is limited to the basin and with limited distance. Survey of RBZ will be done in three separate distance of 500m, 600m and 700m with all survey parameters evaluated accordingly. *Figures 4.7, 4.8 and 4.9*

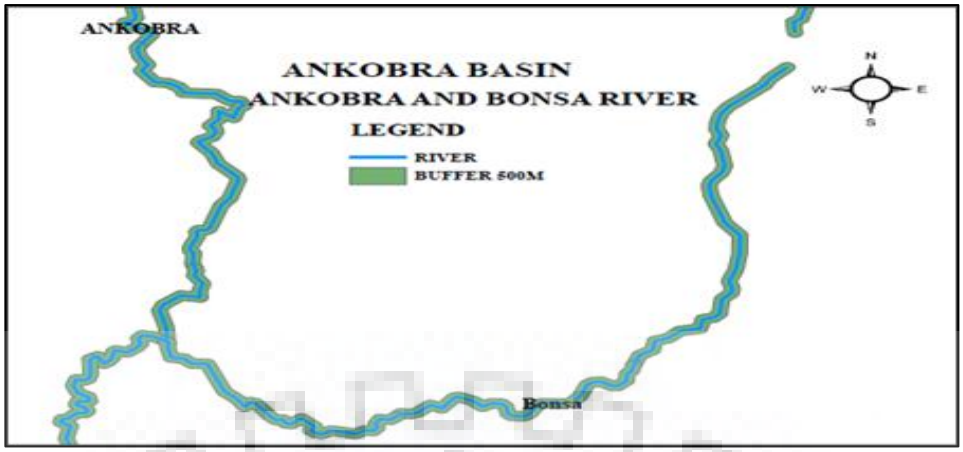


***Figure 4.7**: Riparian buffer zoning for 500m*

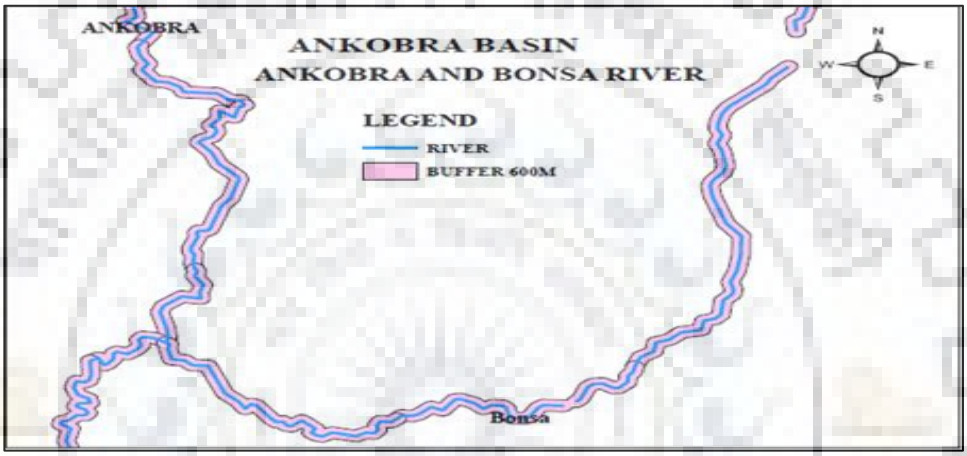


***Figure 4.8**: Riparian buffer zoning for 600m*

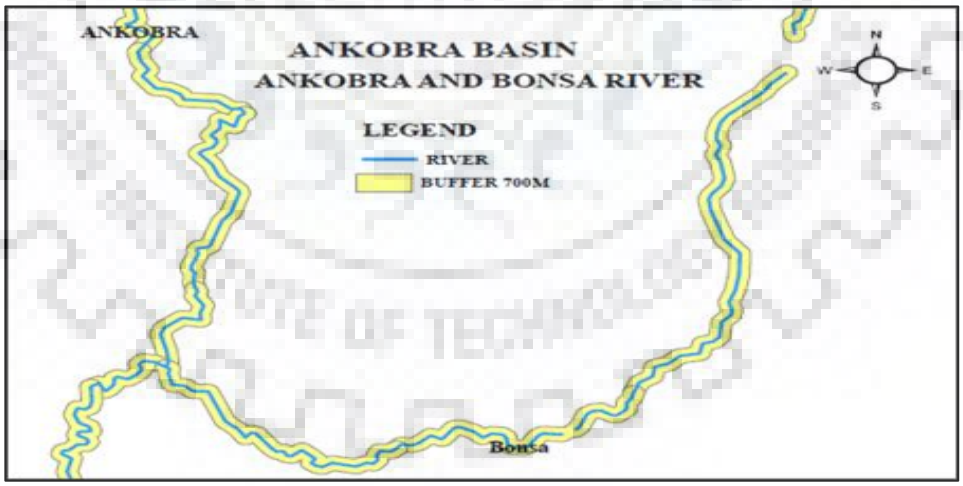


***Figure 4.9**: Riparian buffer zoning for 700m*

4.3.2. Hydro Power potential

The 90 % dependable year flow series is got from the 20-year flow series for the period from 1996 to 2016 as tabulated below.

The annual discharge data for the year 1996 to 2016 has been decided in descending order. The percentage probability of a flow degree being equal or exceeded has been projected by the Weibull's formula. If 'n' numbers of data are used, the plotting position of any discharge 'Q' is:

P = (m/ (n+1))*100%

Where m = discharge order number

n = number of data and

P = probability of flow magnitude being equaled or exceeded (percentage)

See appendices 1 - 7

***Table 4.7**: average yearly discharge of Ankobra river basin*

Year	Discharge Q cumecs
1996	1978.0
1997	2045.0
1998	3230.0
1999	3619.0
2000	2219.0
2001	5744.0
2002	1823.0
2003	2699.0
2004	2450.0
2006	2990.0
2007	3722.0
2008	3896.0
2009	4827.0
2010	5378.0
2011	3885.0
2012	3465.0
2013	3996.0
2014	3644.0
2015	2301.0

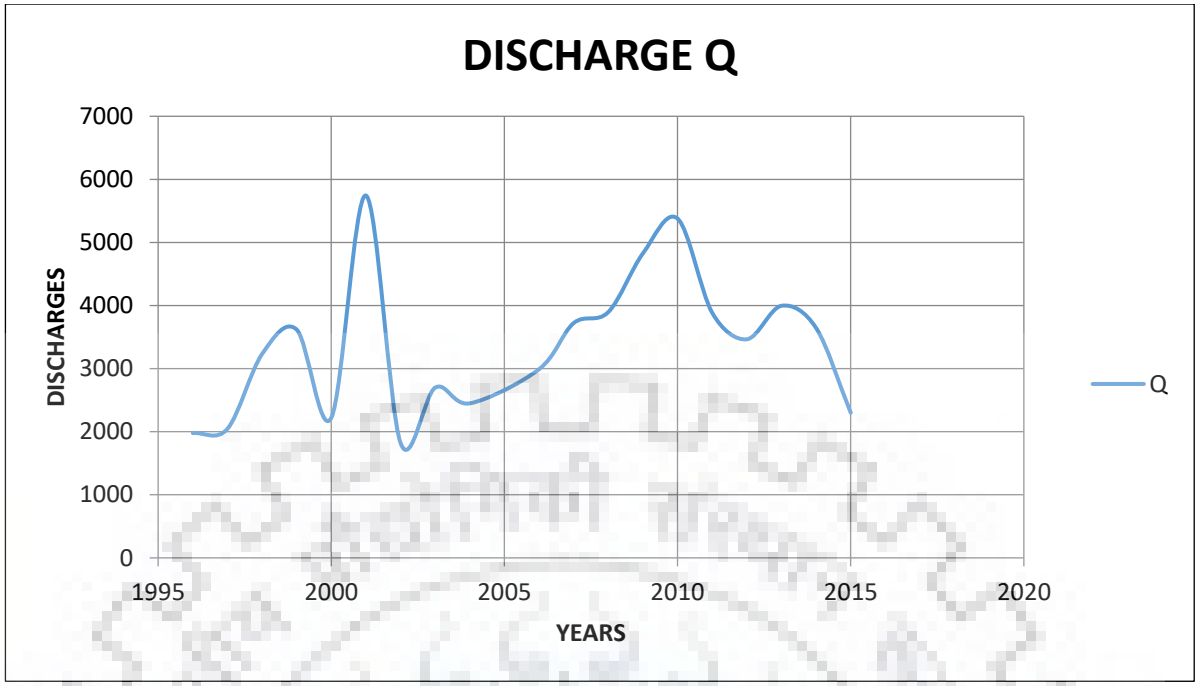


***Figure 4.10**: Yearly discharge curve*

ANNUAL DEPENDABILITY 1996 - 2016				
Rank	**Year**	**Discharge Q m³/sec**	**Weibull's Distribution m/(n+1)**	**Dependability (in %)**
1	2001	5744.0	0.05	**4.76**
2	2010	5378.0	0.10	**9.52**
3	2009	4827.0	0.14	**14.29**
4	2013	3996.0	0.19	**19.05**
5	2008	3896.0	0.24	**23.81**
6	2011	3885.0	0.29	**28.57**
7	2007	3722.0	0.33	**33.33**
8	2014	3644.0	0.38	**38.10**
9	1999	3619.0	0.43	**42.86**
10	2012	3465.0	0.48	**47.62**
11	1998	3230.0	0.52	**52.38**
12	2006	2990.0	0.57	**57.14**
13	2003	2699.0	0.62	**61.90**
14	2004	2450.0	0.67	**66.67**
15	2015	2301.0	0.71	**71.43**
16	2000	2219.0	0.76	**76.19**
17	1997	2045.0	0.81	**80.95**
18	1996	1978.0	0.86	**85.71**
19	2002	1823.0	0.90	**90.48**

***Table 4.8**: WRC report, annual dependability from 1996-2016*

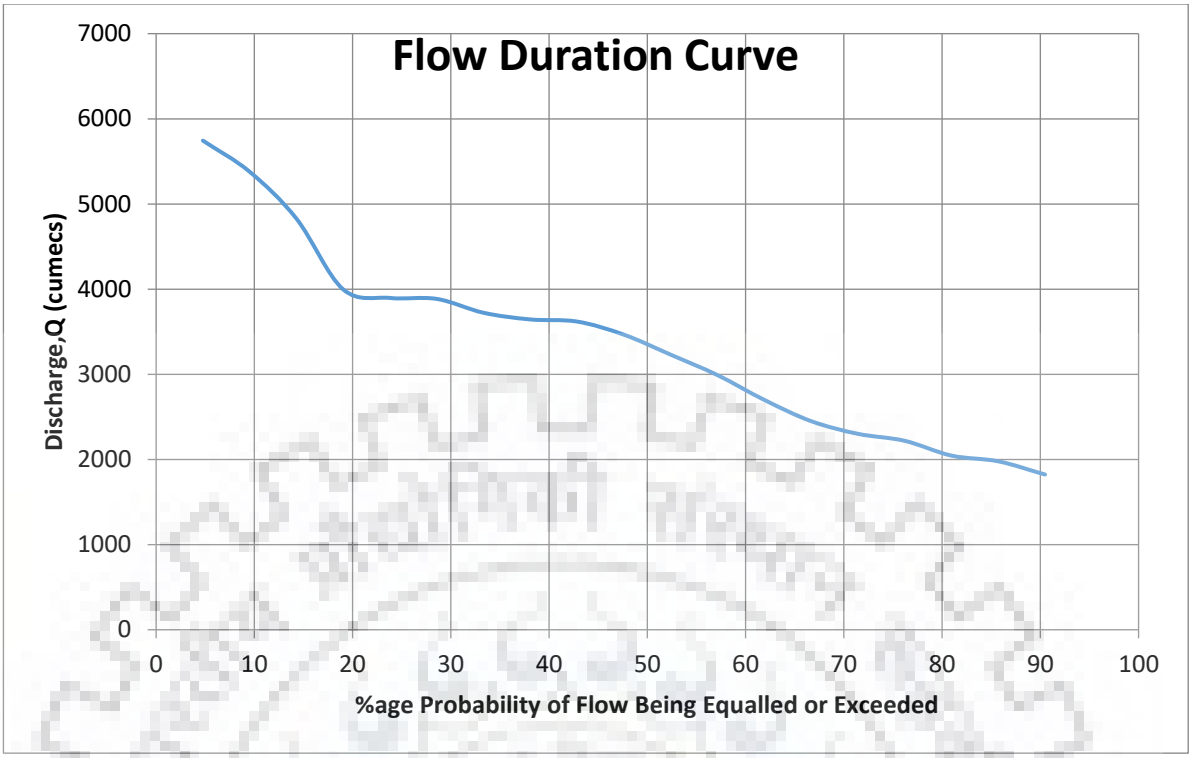


***Figure 4.11**: Flow duration curve*

From the DEM (figure 1.3), take the average head of the range

The power generated is estimated as:

$P = g*Q*H*\eta/1000$

Where P- power in 'MW'

Q – Discharge in 'm^3/s'

H – Net Head in 'm'

g – '9.81 $m/s^{2'}$

η - Combined efficiency '87.36%' (turbine and generator etc.)

Thus enhance:

- Accessible reach of river banks throughout
- Maintained sedimentation, controlled erosion, perennial water availability, better navigational management, environmental features, more and better local engagement for livelihood generation and improved life etc.
- Control deprivation of the river, land mass and environment.

***Table 4.9**: Power potential and discharges with average elevation of 38m*

	2011			2012			2013		
MONTHS	Q m^3/s	Net-Head m	Power P(MW)	Q m^3/s	Net-Head m	Power P(MW)	Q m^3/s	Net-Head m	Power P(MW)
Jan	50	38	16	38	38	12	41	38	13
Feb	130	38	42	246	38	80	57	38	18
Mar	203	38	66	522	38	169	133	38	43
Apr	834	38	270	694	38	225	562	38	182
May	904	38	293	750	38	243	1114	38	361
Jun	117	38	38	112	38	36	262	38	85
Jul	395	38	128	197	38	64	90	38	29
Aug	586	38	190	455	38	147	744	38	241
Sept	453	38	147	246	38	80	796	38	258
Oct	91	38	29	90	38	29	74	38	24
Nov	68	38	22	66	38	21	81	38	26
Dec	54	38	17	49	38	16	42	38	14
	3885			**3465**			**3996**		

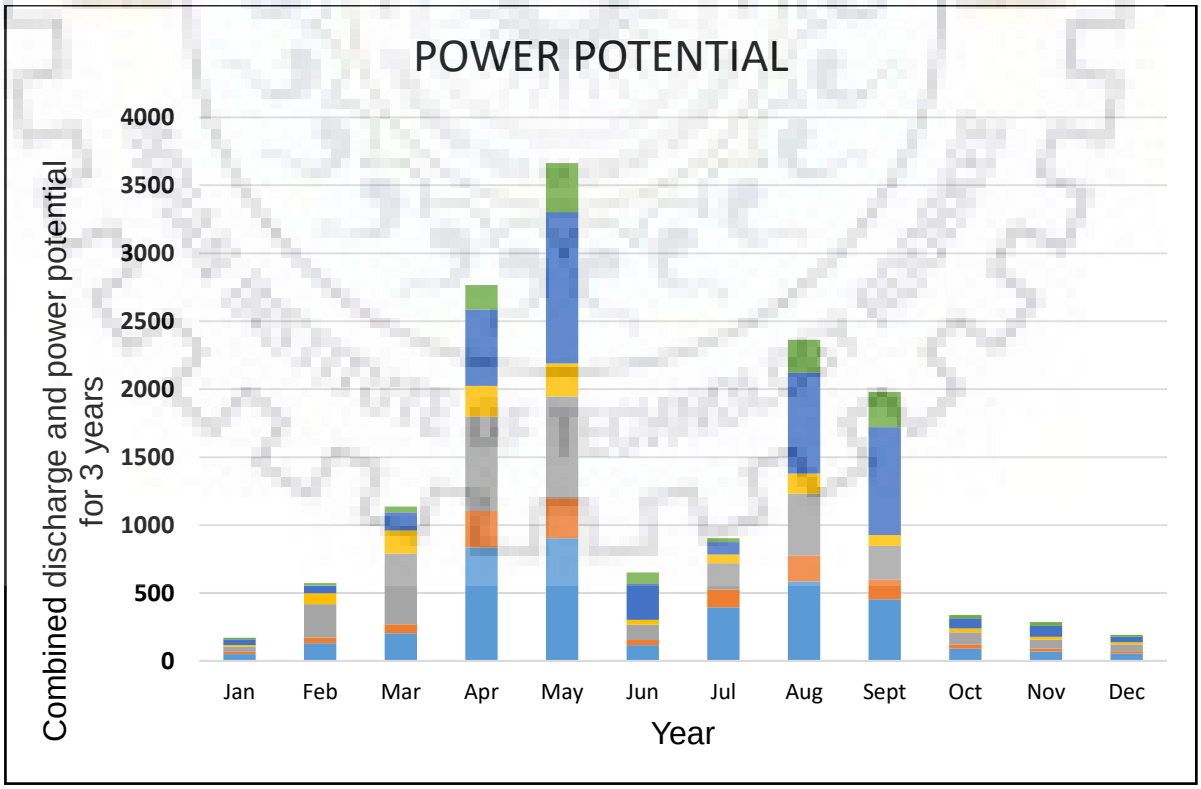


***Figure 4.12**: Power potential and discharge graph with 38m average elevation*

Table 4.10: *Power potential and discharges with average elevation of 421m*

	2011			2012			2013		
MONTHS	Q m^3/s	Net-Head m	Power P(MW)	Q m^3/s	Net-Head m	Power P(MW)	Q m^3/s	Net-Head m	Power P(MW)
Jan	50	421	180	38	421	137	41	421	148
Feb	130	421	468	246	421	887	57	421	205
Mar	203	421	732	522	421	1881	133	421	479
Apr	834	421	3005	694	421	2501	562	421	2025
May	904	421	3258	750	421	2703	1114	421	4015
Jun	117	421	422	112	421	404	262	421	944
Jul	395	421	1423	197	421	710	90	421	324
Aug	586	421	2112	455	421	1640	744	421	2681
Sept	453	421	1632	246	421	887	796	421	2869
Oct	91	421	328	90	421	324	74	421	267
Nov	68	421	245	66	421	238	81	421	292
Dec	54	421	195	49	421	177	42	421	151
	3885			**3465**			**3996**		

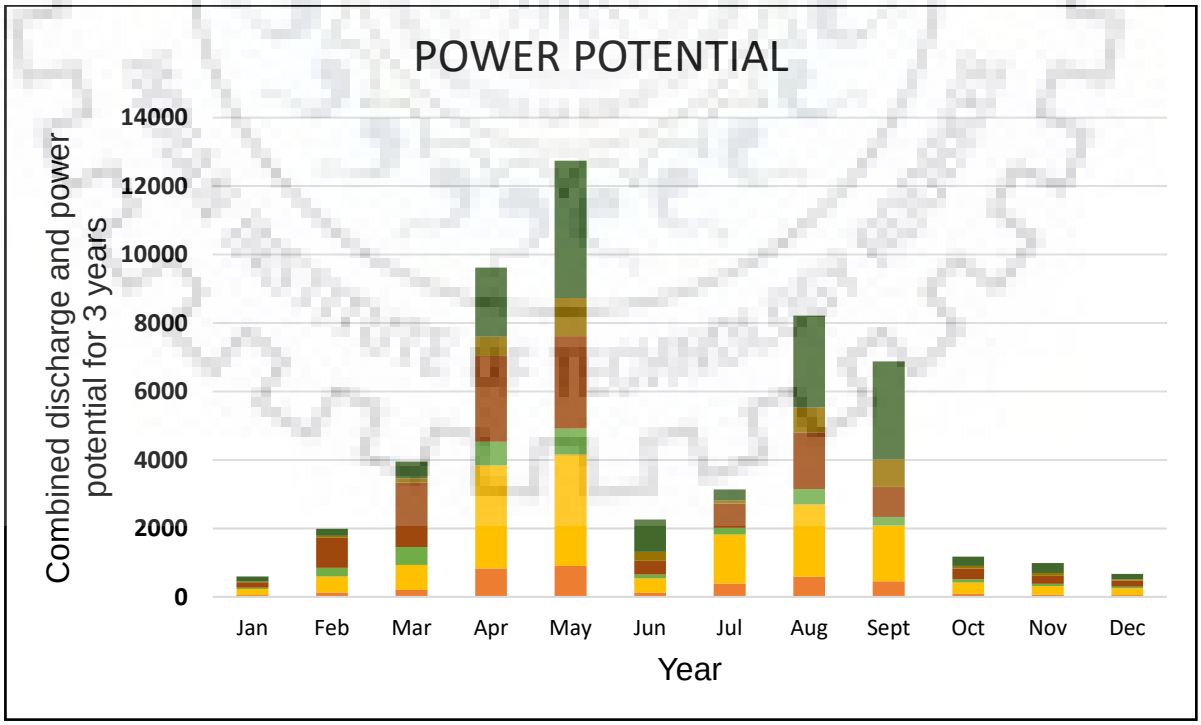


Figure 4.13: *Power potential and discharge graph with 421m average elevation*

The actual net head accessible to the project depends on the type of intake structure used, turbine brand and assortment of water performer system.

***Table 4.11**: Minimum, maximum discharge and power potential with respect to different elevations*

YEARS	HEAD M	DISCHARGE M^3/s		POWER POTENTIAL MW	
		MINIMUM	MAXIMUM	MINIMUM	MAXIMUM
2011	38	50	904	16	293
2012	**38**	38	750	**12**	**243**
2013	38	41	1114	13	361
2011	97	50	904	42	751
2012	97	38	750	32	623
2013	97	41	1114	34	926
2011	145	50	904	62	1123
2012	145	38	750	47	932
2013	145	41	1114	51	1384
2011	221	50	904	94	1708
2012	221	38	750	72	1417
2013	221	41	1114	77	2105
2011	421	50	904	180	3258
2012	421	38	750	137	2703
2013	**421**	41	1114	**148**	**4015**

Average annual discharge = 63911.0/19 =3363.74m^3/s

Average annual head = 37+97+146+224+421/5 = 925/5 = 185m

g = 9.81m/s^2

ɳ-Combined efficiency = 87.36% (turbine & generator etc.)

Annual power potential = g*Q*H*ɳ/1000

= 9.81*3363.74*185*.8736/1000

= **5333.05 MW**

Therefore, annual power potential for the ankobra basin is **5333.05 MW**

4.3.3. Advancement Plans for Revitalization and Development of Ankobra River Basin

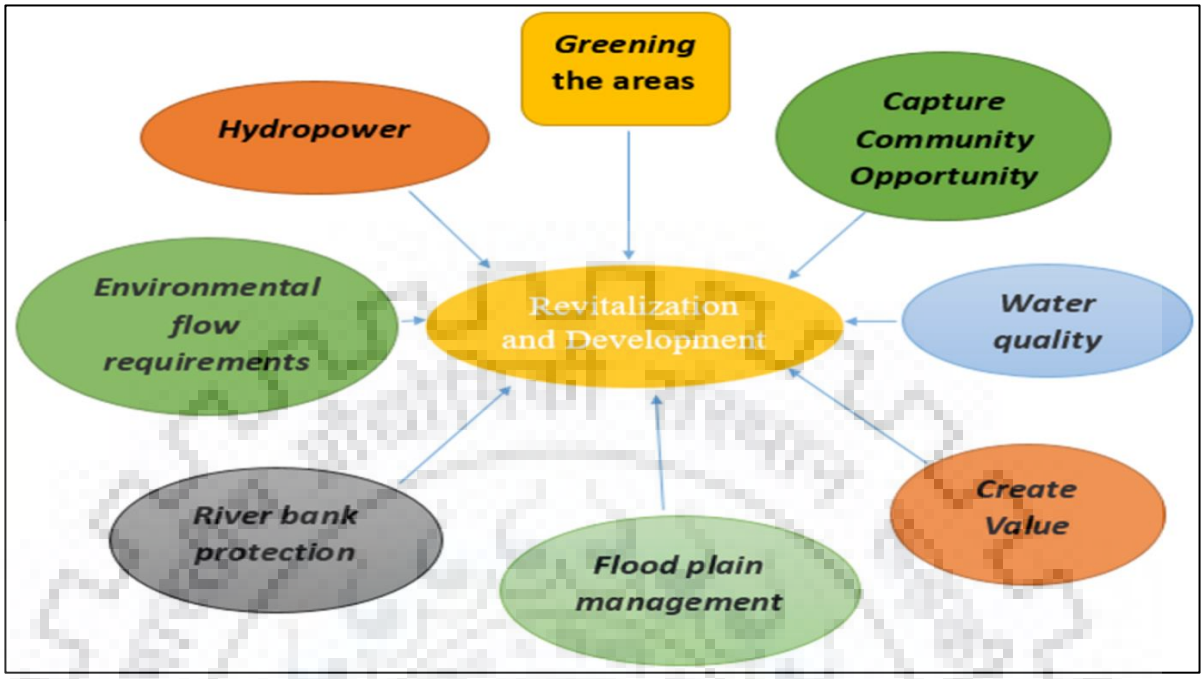


***Figure 4.14**: Advanced Plans chart for revitalization and development of Ankobra river basin*

The land covers/use changes in the Ankobra River basin can be credited to anthropogenic drivers, which can be assembled into two, in particular, worldwide and neighbourhood factors. The worldwide variables incorporate globalization of agribusiness, urbanization, universal exchange administrations and worldwide legislative issues, while the nearby factors incorporate populace development, urbanization, movement, money related advancement and government arrangement [18]. The recorded deforestation in the Ankobra River basin was affected by nearby populace development (Ghana Statistical Service, 2005; Kusimi, 2008; Ghana Statistical Service, 2013), horticultural extensification (Kusimi, 2008; Sutton and Kpentey, 2012), timber logging (Asante, 2005; Kusimi, 2008) and expanded surface mining exercises (Akabzaa and Darimani, 2001) since 1986, when the usage of the basic change program of the World Bank, changed Ghana's economy (Barbier, 2000) and besides, extended outside mining, timber and direct enthusiasm for the cultivating organizations. Along these lines, anthropogenic land cover changes are caused by both adjoining and worldwide drivers, while the effects are to a great extent felt at the nearby scale.

The study was carried out across a width of 500, 600 and 700 meters area of Riparian buffer zones of the selected reach of the basin on the left and right banks. Much variance was observed in both during the investigation. Some areas were subjugated by illegal mining activities and agricultural practice, but fewer areas were wrapped with forests and trees. It was found that in some areas people were converting areas protecting the basin into mining zones.

Thus successive application of the riparian buffer zones will ensure revitalization water quality through enhanced flood storage, to ease back stream speeds to empower reintroduction of vegetation; improved water quality, through local scale stormwater treatment at River conjunctions, and limited "treatment porches" at storm deplete outfalls; improved free inside the channel by means of patios and inclines, little pocket parks and ponded zones; and a reestablished riparian biological community. These rules for the stormwater administration and the reasonable building will propel the City's "green plan."

Keeping up or setting up vegetation in, or on the banks of, waterways impressively improve stream scenes (Coux and Welcomme 1998).

- The roots of tree increment the resistance quality of the waterway tier and secure it in contradiction of disintegration.
- Undergrowth along these lines balances out floodplains and channels and lessens disintegration.

The lessening in speed diminishes sheer weight on the channel bank, which prompts the statement of fine dregs and rise of water levels at a given release.

Vegetation may along these lines constrict surge streams by moderating speeds and making water spread higher on the floodplain (Friedman and Auable 2000). Enhanced silt trapping in the riparian cushion strips gives one of only a handful couple of chances to prevent disintegrated soil from leaving the catchment without obstructing the streams, yet riparian support strips were not set up to limit residue conveyance to the waterway.

Automation*:* will improve waterway renewal and advancement through; making Mining Safer (Automation gives mines more superior control over their fabrication processes and, subsequently, permits them to deliver a advanced quality completed item.), Safer Mining through Better Oversight (Automating mining forms permits the mine condition overall to be all the more firmly observed. In doing so, the previously mentioned hazards, such as air quality, can be assessed quickly and with a great degree of accuracy, if and when dangers to workers arise.), Environmentally Friendly Mining (the superior degree of control over the mining practice offered by automation allows mines to assess their environmental impact more

accurately. Restricting waste delivered by the mining procedure and lessening outflows caused by the unneeded task of hardware are only a couple of the manners by which mechanized innovation can help mines to wind up greener). And Fewer Hazards for Workers (Automation also ensures that tasks are completed correctly and consistently every time. Accordingly, the "human mistake" factor caused by the erroneous task of a machine or a slip by in consideration can be disposed of.)

Greening*:* the areas expand the River's impact into nearby neighborhoods, will bring about production of a nonstop River Greenway that fills in as the City's "green spine;" recouple neighborhoods to the River through an arrangement of "green lanes;" recover underutilized or brownfield destinations in stop poor regions as neighborhood parkland, and joining stormwater administration hones into every single open scene; improve River character through mark spans and doors, and through modified occasions; and fuse open workmanship along the River.

Capture Community Opportunity: Recently, communities have turned their back on the Rivers, viewing it as an unsafe, unpleasant place that predominantly functions to transport storm flows and unpleasant water. This present Plan's vision calls for changing the River into a sheltered, open, sound, green, and celebrated place, with the objective of making the River the concentration of action and cultivating metro pride. For instance, even modern territories can be changed over to new "eco-mechanical" parks that enhance the living and workplace by giving open space openings, access to the River, and cleaner, higher-paying employment for City inhabitants.

The objectives for capturing community prospects comprise incorporate connecting with inhabitants in the community planning process. Neighborhood-by-neighborhood accord building can help distinguish the best zones for reorienting advancement and open space while empowering neighborhood improvement, strengthening, and reinvestment.

Correlative objectives include providing opportunities for educational and public facilities and celebrating the cultural legacy of the River.

By restoring horizontal connectivity will be created new opportunities for local riparian communities.

The study identifies these opportunities, how engaging residents in the community planning process and how:

- participate residents in the community planning process and consensus building;
- provide opportunities for educational and public facilities;
- The cultural legacy of the river and foster civic pride.

For hydropower install capacity, studies specify that installed capacity of 12 MW - 243 MW for a net head of 38m and 148 MW – 4015 MW for a net head of 421m, comprising of 3 producing units of 81 MW and 1338 MW each respectively, would be the most favourably option.

Due to the accessibility of average discharge on the Ankobra river basin with the main tributary of Bonsa River, the basin is more reliable for development of hydropower project. The 90% annual dependability has been derived from the power potential study. Thus a design flood of 1823m^3/s of the basin is recommended based on the annual dependability of the basin. The anticipated hydropower project can be a runoff- the-river scheme.

Financially, the hydropower on the basin will offer open doors for the ideal utilization of joined assets. Lessen operation expenses and ozone-depleting substance emanation and different contaminations on the basin will be revived and built up the whole basin. Provision of jobs opportunities for the communities as well as more reliable and alternative supply of electricity from interconnection network in case of power failure or shortage. A more advanced approach of less to no head but high discharge kinetic turbines once placed on the stream will be a faster green generation scheme to remotely living isolated villagers and habitats.

Environmental flow requirements: For environmental "maintenance" on the river flow to endure, minimum flow requirements on the water at the downstream for observation which focuses on stream framework. Evaluation base stream prerequisites was founded on a stumpy-stream recurrence investigation for month to month stream information .A gross water balance equation of demand supply pattern considering the need of revitalizing the stream can be periodically instituted dynamically for correction.

Water quality: Occasional changes in stream and temperature and reacting natural movement causes water quality to vary between rivers because of climate and the major land acknowledgment as the year progressed. The impact of human activity on water quality and quantity changes the drainage outlines to rivers and the corresponding chemical elements and sediments the water may be carrying.

Rivers used as sewage or liquid waste dumps and nourish storm-water depletes that have depleted messy urban zones into them. Ailment causing specialists, oxygen-requesting squanders, water-dissolvable inorganic chemicals, inorganic plant supplements, natural chemicals, dregs or deferred issue, water-solvent radioactive isotopes and warm toxins are for the most part because of contamination in the stream basin.

Diminishing plenitudes and biodiversity of the basin, influence the aquatic biological communities' capacity to work proficiently. Recovery of corrupted frameworks requires that consideration is given to the nature of the water, including the amount and the physical characteristics of the bowl. Unless all these are appropriate, arranged restoration might be unsuccessful.

Improve water quality to recondition impaired waters, associations with EPA, the agency's capability to validate results in watershed management, the ability to use adaptive supervision in land management plan implementation and the Improving National Environmental Policy Act scrutinizes and compliance are collective driver desired as an active tool for the agency to achieve a standardized National Best Management Practice (BMP)

Flora-Fauna, Aquatic Lives: These markers were extremely effective in separating over a scope of anthropogenic agitations. They are additionally reliable after some time, adaptable and broadly versatile.

The overall proportion of presumed errors of classification was roughly the same for both indices.

The TMI is simple to design and is good at assessing anthropogenic impacts. It does not need many environmental parameters or initial selection of reference sites to be built. However, it also doesn't implicitly integrate all major environmental factors that cause, or at least explain, the patterns of assemblage composition and distribution within and among water bodies at various spatial-temporal scales under natural conditions.

Nevertheless, it becomes more intricate and its presentation requires a preliminary selection of reference sites, a difficult and subjective task.

MMI ought to be lauded as more fitting for the international basin, while the TMI is most appropriate to a provincial or group basin.

River bank protection: The beaver (Castor fibre), is locally broad, and now has more accessible natural surroundings and tunnel destinations, it is currently utilizing the reconnected riverside branches; The reduction of human disturbance resulting from the elimination of the forest roads, is causative to the preservation and reproducing of imperilled winged animals, for example, the dark stork (Ciconia nigra) and the white-followed hawk (Haliaetus albicilla).

As part of an existing flood-management plan that contains floodwater on sports grounds, the river banks have been raised. Access to the river, however, is compromised and offers limited amenity. New innovative soil bioengineering or soft biotechnical engineering techniques, such

as bank protection using geotextiles and terraced geocells, provide a more natural commencement to rivers than firm engineering practices.

These have many limitations, however, and are often best used together with hard engineering rehabilitation tools such as riprap and gabions.

Floodplain management: Improved flood alleviation is not the only benefit of the project. The region is greatly species-rich and its prairie environments are ensured by the Birds and Habitats Directives.

Create Value: Making the River green and manageable is estimated to transform an underestimated asset into a valued feature. This Plan's vision is also about creating value—improving the quality of life for residents, increasing the attractiveness of the City as a place to live and work, and increasing economic prosperity. Core elements of this idea include empowering communities by encouraging participation and consensus-building, generating opportunities for sustainable, economic reinvestment, and adding value and providing an equitable distribution of opportunities to underserved neighbourhood along the River.

CHAPTER-5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions and Recommendations

From 1986 to 2016, multi-temporal images of the area were classified indicates that the Ankobra River Basin is largely covered by dark forests and recently decline at 2.37%. The analysis additionally demonstrates the possible drivers that incorporate universal exchange, neighborhood populace development, horticulture escalation and urbanization.

Small-scale miners termed Galamsey using mercury poisons the stream for their short term economic advantages. The small-scale miners may be influenced through customized training and educational programs accompanied with technical and financial assistance to abandon the practice.

Buffer zones positioned close to the source of surface water pollution are therefore more likely to succeed in controlling water quality.

Three main activities or measures formed the basis for a successful rehabilitation effort. To moderate the impacts of hard designing practices, these were utilized on the grounds that they were earth delicate river conservation activities, soil bioengineering or delicate biotechnical engineering practices.

Riparian zones grow regular vegetation on both sides of the stream bank. Pollutants inflowing a stream from overflow controls disintegration and giving living planetary and supplement contribution to the stream are essential focal points.

Riparian buffers as the most valued protection a stream system has in contradiction of outside influences, and its benefit includes;

- Provides organic material as food for invertebrate, fish and wildlife;
- Supplies large and small pieces of woody debris that provide habitat for fish, invertebrates and amphibians;
- controls how sunlight reaches the river basin and also a moderator temperature;
- reduces erosion and river banks Stabilization;

- Roots of many plants trap and hold the sediments, as well as filters sediment and material from overland runoff;
- Sub-surface flows and nutrients from overland are absorbed; and
- It limits flooding sway through capacity, moderate discharges from overwhelming downpours and a capture attempt.

In terms of hydropower, it is a more secure alternative, Hydroelectric power can be depended upon, availability of green energy, it can be re-utilized, its dependable, it can be directed, it is less expensive, it averts Floods, make available employment opportunities and as tourist attraction sites.

Industrial processes such as drilling, blasting, and transportation are enhanced through remote monitoring and control of equipment as miners are allowed to automate.

Consistent operations, balanced infrastructure, improved communications are gain continuous through efficiency. Creating new and different jobs by mining companies through automation.

Investing in automation solutions has the potential to open a mining company to the threat of hackers.

Automation can enhance river revitalization and development through; Decreased Process Variability, Higher Quality Product, Lower Operating Costs and Better Monitoring.

Subsequently, Rivers Revitalization Plan rundowns an open framework program that will encourage the reclamation, redevelopment and revitalization the area. Revitalized rivers will enhance water quality, give green space to accelerate health progress in poor and socially excluded groups, enhance surge assurance and diminish our reliance on imported water, restore a functional ecosystem, enhance river identity, foster civic pride, provision of hydropower, improve the quality of life.

A revitalized stream with support to the population for its livelihood is the future to hold the promise of human beings living along the river banks dependent on each other peacefully in nature. The proposed schemes brought in practice will deliver in that direction.

A holistic approach to ensure suitable management packages beneficial for biodiversity and reducing flood risk, erosion, habitat loss and damage to any structural integrity etc., as well as

improving access where necessary and enhancing the aesthetics of the area by programmes tailored to requirements are to be adopted.

With the purpose to revitalize the Ankobra stream, the environment of the river is to improvise for natural habitat, water quality, recreation, green space, and economic values. The compromised water quality, accumulation of trash and wastage, mining contributors to polluted waters, lack of habitat, risks to public safety, inadequate green buffer zone and farming fields, lack of planned habitation and loss of jobs to be managed well.

The advance plans to support the revitalization of the Ankobra river basin are feasible to implement subject to the support of revised legislation, governmental will power, appropriate investment of capital, involvement of people and proper technical detailing because these measures will provide long term benefit to the communities and the nation at large.

The project proposes to advance by public involvement during the development of the revitalization measures and alternatives. The revitalization management framework well controlled by legal authority that are discussed here and the conclusions presented are for the mitigation of the adverse impacts associated with air quality, water quality, biological resources, land use, deforestation, public health and safety, transportation, socioeconomic resources, environmental justice, agricultural resources, geology, soils erosion, mineral aspect, green energy reliance, flood management, recreation, utilities and infrastructure, and aesthetic resources.

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APPENDICES

Appendix 1

	1996			1997			1998		
MONTHS	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)
Jan	21	42	8	19	42	7	27	42	10
Feb	25	42	9	22	42	8	36	42	13
Mar	121	42	44	48	42	17	94	42	34
Apr	155	42	56	152	42	55	493	42	177
May	416	42	150	417	42	150	607	42	218
Jun	489	42	176	497	42	179	619	42	223
Jul	292	42	105	271	42	98	360	42	130
Aug	55	42	20	73	42	26	290	42	104
Sept	73	42	26	28	42	10	74	42	27
Oct	247	42	89	411	42	148	493	42	177
Nov	47	42	17	69	42	25	84	42	30
Dec	37	42	13	38	42	14	53	42	19
	1978			2045			3230		

Appendix 2

	1999			2000			2001		
MONTHS	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)
Jan	43	42	15	29	42	10	57	42	21
Feb	50	42	18	32	42	12	62	42	22
Mar	66	42	24	43	42	15	123	42	44
Apr	381	42	137	116	42	42	497	42	179
May	792	42	285	413	42	149	1066	42	384
Jun	812	42	292	779	42	280	1492	42	537
Jul	92	42	33	70	42	25	159	42	57
Aug	201	42	72	110	42	40	626	42	225
Sept	452	42	163	241	42	87	1201	42	432
Oct	543	42	195	214	42	77	280	42	101
Nov	117	42	42	116	42	42	91	42	33
Dec	70	42	25	56	42	20	90	42	32
	3619			2219			5744		

Appendix 3

	2002			2003			2004		
MONTHS	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)
Jan	32	42	12	37	42	13	33	42	12
Feb	36	42	13	40	42	14	40	42	14
Mar	50	42	18	61	42	22	49	42	18
Apr	100	42	36	184	42	66	149	42	54
May	394	42	142	476	42	171	555	42	200
Jun	419	42	151	596	42	215	498	42	179
Jul	174	42	63	159	42	57	88	42	32
Aug	164	42	59	370	42	133	312	42	112
Sept	288	42	104	370	42	133	307	42	111
Oct	41	42	15	265	42	95	202	42	73
Nov	70	42	25	90	42	32	149	42	54
Dec	55	42	20	51	42	18	68	42	24
	1823			2699			2450		

Appendix 4

	2005			2006			2007		
MONTHS	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)
Jan	24	42	9	29	42	10	35	42	13
Feb	27	42	10	33	42	12	45	42	16
Mar	29	42	10	126	42	45	63	42	23
Apr	196	42	71	186	42	67	333	42	120
May	287	42	103	295	42	106	985	42	355
Jun	308	42	111	991	42	357	1062	42	382
Jul	68	42	24	73	42	26	78	42	28
Aug	63	42	23	56	42	20	119	42	43
Sept	221	42	80	601	42	216	611	42	220
Oct	113	42	41	502	42	181	256	42	92
Nov	48	42	17	42	42	15	100	42	36
Dec	39	42	14	56	42	20	35	42	13
	1423			2990			3722		

Appendix 5

	2008			2009			2010		
MONTHS	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)
Jan	35	42	13	53	42	19	81	42	29
Feb	40	42	14	105	42	38	122	42	44
Mar	164	42	59	140	42	50	369	42	133
Apr	540	42	194	474	42	171	628	42	226
May	715	42	257	756	42	272	1104	42	397
Jun	1085	42	391	1334	42	480	1359	42	489
Jul	83	42	30	76	42	27	114	42	41
Aug	126	42	45	874	42	315	153	42	55
Sept	699	42	252	535	42	193	1041	42	375
Oct	292	42	105	267	42	96	300	42	108
Nov	68	42	24	156	42	56	49	42	18
Dec	49	42	18	57	42	21	58	42	21
	3896			4827			5378		

Appendix 6

	2011			2012			2013		
MONTHS	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)
Jan	50	42	18	38	42	14	41	42	15
Feb	130	42	47	246	42	89	57	42	21
Mar	203	42	73	522	42	188	133	42	48
Apr	834	42	300	694	42	250	562	42	202
May	904	42	325	750	42	270	1114	42	401
Jun	117	42	42	112	42	40	262	42	94
Jul	395	42	142	197	42	71	90	42	32
Aug	586	42	211	455	42	164	744	42	268
Sept	453	42	163	246	42	89	796	42	287
Oct	91	42	33	90	42	32	74	42	27
Nov	68	42	24	66	42	24	81	42	29
Dec	54	42	19	49	42	18	42	42	15
	3885			3465			3996		

Appendix 7

	2014			2015			2016		
MONTHS	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)	Q	Net-Head	Power P(MW)
Jan	58	42	21	39	42	14	0	42	0
Feb	70	42	25	52	42	19	0	42	0
Mar	257	42	93	71	42	26	0	42	0
Apr	716	42	258	386	42	139	0	42	0
May	925	42	333	469	42	169	0	42	0
Jun	239	42	86	419	42	151	0	42	0
Jul	130	42	47	238	42	86	0	42	0
Aug	532	42	191	356	42	128	0	42	0
Sept	493	42	177	176	42	63	0	42	0
Oct	101	42	36	95	42	34	0	42	0
Nov	77	42	28	0	42	0	0	42	0
Dec	46	42	17	0	42	0	0	42	0
	3644			2301					

Appendix 8

	Mining (illegal)	Navigation	Agriculture	Hydropower	Biological degradation	Urbanization and infrastructure development	Natural causes	Water quality
	0.118	0.132	0.132	0.118	0.118	0.132	0.118	0.132
	0.135	0.122	0.135	0.135	0.135	0.108	0.122	0.108
	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
	0.118	0.132	0.118	0.147	0.103	0.118	0.118	0.147
	0.143	0.114	0.129	0.114	0.100	0.114	0.143	0.143
	0.120	0.133	0.133	0.107	0.133	0.120	0.120	0.133
	0.105	0.132	0.118	0.132	0.132	0.118	0.132	0.132
	0.130	0.117	0.130	0.117	0.130	0.130	0.130	0.117
	0.120	0.107	0.133	0.120	0.133	0.133	0.133	0.120
	0.106	0.121	0.152	0.152	0.106	0.121	0.091	0.152
	0.120	0.133	0.133	0.120	0.120	0.133	0.107	0.133
	0.139	0.111	0.125	0.139	0.111	0.125	0.111	0.139
	0.137	0.123	0.137	0.110	0.123	0.123	0.110	0.137
	0.128	0.115	0.128	0.128	0.128	0.128	0.128	0.115
	0.108	0.135	0.122	0.135	0.135	0.108	0.122	0.135
	0.127	0.127	0.127	0.114	0.127	0.127	0.127	0.127
	0.120	0.133	0.133	0.133	0.120	0.107	0.120	0.133
	0.132	0.132	0.118	0.105	0.118	0.132	0.132	0.132
	0.115	0.128	0.128	0.115	0.128	0.128	0.128	0.128
	0.119	0.149	0.134	0.104	0.090	0.119	0.134	0.149
	0.117	0.130	0.130	0.117	0.130	0.117	0.130	0.130
	0.117	0.130	0.117	0.130	0.130	0.117	0.130	0.130
	0.109	0.141	0.156	0.094	0.109	0.125	0.109	0.156
	0.139	0.097	0.125	0.139	0.125	0.111	0.139	0.125
	0.130	0.145	0.087	0.101	0.116	0.130	0.145	0.145
	0.096	0.123	0.110	0.137	0.137	0.137	0.123	0.137
	0.132	0.118	0.132	0.105	0.132	0.132	0.132	0.118
	0.095	0.122	0.135	0.122	0.135	0.122	0.135	0.135
	0.091	0.136	0.121	0.136	0.106	0.121	0.136	0.152
	0.092	0.138	0.154	0.123	0.108	0.138	0.092	0.154
	0.139	0.125	0.111	0.139	0.083	0.125	0.139	0.139
	0.137	0.123	0.110	0.137	0.123	0.110	0.123	0.137
	0.115	0.148	0.131	0.098	0.115	0.148	0.098	0.148
	0.088	0.132	0.118	0.147	0.132	0.103	0.132	0.147
	0.125	0.139	0.111	0.125	0.139	0.111	0.139	0.111
	0.108	0.138	0.123	0.154	0.092	0.092	0.138	0.154
	0.111	0.143	0.111	0.127	0.143	0.095	0.127	0.143
	0.113	0.145	0.113	0.129	0.113	0.097	0.129	0.161
	0.117	0.130	0.130	0.130	0.117	0.130	0.117	0.130
	0.128	0.128	0.128	0.115	0.128	0.128	0.128	0.115
	0.106	0.121	0.152	0.136	0.106	0.106	0.121	0.152
	0.117	0.130	0.130	0.130	0.117	0.130	0.130	0.117
	0.118	0.147	0.118	0.132	0.088	0.118	0.132	0.147
	0.137	0.110	0.137	0.137	0.110	0.123	0.110	0.137
	0.130	0.117	0.130	0.104	0.130	0.130	0.130	0.130

	0.115	0.128	0.128	0.115	0.128	0.128	0.128	0.128
	0.123	0.137	0.137	0.110	0.123	0.123	0.110	0.137
	0.134	0.149	0.119	0.104	0.119	0.134	0.090	0.149
	0.137	0.123	0.137	0.110	0.096	0.137	0.123	0.137
	0.132	0.118	0.105	0.132	0.118	0.132	0.132	0.132
	0.104	0.134	0.104	0.134	0.119	0.149	0.134	0.119
	0.113	0.127	0.113	0.141	0.099	0.141	0.127	0.141
	0.097	0.125	0.139	0.111	0.139	0.111	0.139	0.139
	0.132	0.118	0.105	0.132	0.118	0.132	0.132	0.132
	0.121	0.138	0.121	0.103	0.121	0.138	0.121	0.138
	0.122	0.135	0.095	0.135	0.122	0.135	0.122	0.135
	0.139	0.111	0.125	0.097	0.139	0.125	0.125	0.139
	0.127	0.141	0.113	0.127	0.141	0.099	0.127	0.127
	0.099	0.141	0.141	0.113	0.127	0.141	0.113	0.127
	0.111	0.139	0.111	0.125	0.139	0.111	0.125	0.139
	0.123	0.110	0.137	0.123	0.137	0.096	0.137	0.137
	0.129	0.143	0.114	0.143	0.100	0.129	0.129	0.114
	0.108	0.135	0.122	0.108	0.135	0.135	0.122	0.135
	0.120	0.133	0.107	0.120	0.133	0.120	0.133	0.133
	0.111	0.125	0.139	0.097	0.125	0.139	0.125	0.139
	0.125	0.139	0.111	0.125	0.139	0.125	0.111	0.125
	0.133	0.120	0.107	0.133	0.120	0.133	0.120	0.133
	0.100	0.129	0.114	0.129	0.114	0.143	0.129	0.143
	0.103	0.132	0.103	0.132	0.147	0.132	0.118	0.132
	0.091	0.136	0.121	0.152	0.091	0.136	0.121	0.152
	0.129	0.114	0.129	0.114	0.143	0.129	0.100	0.143
	0.123	0.092	0.138	0.123	0.092	0.138	0.154	0.138
	0.103	0.138	0.121	0.121	0.103	0.155	0.086	0.172
	0.111	0.127	0.143	0.095	0.127	0.095	0.143	0.159
	0.101	0.145	0.130	0.145	0.116	0.130	0.101	0.130
	0.113	0.141	0.099	0.127	0.113	0.127	0.141	0.141
	0.078	0.125	0.109	0.156	0.125	0.109	0.141	0.156
	0.129	0.100	0.143	0.129	0.114	0.143	0.114	0.129
	0.108	0.122	0.108	0.135	0.122	0.135	0.135	0.135
	0.117	0.130	0.130	0.117	0.130	0.130	0.117	0.130
Average Weight	**0.118**	**0.128**	**0.124**	**0.124**	**0.121**	**0.125**	**0.124**	**0.136**

Appendix 9

percentages for individual sub indicators - mining (illegal)							
60	30	20	20	20	30	20	20
10	30	20	40	20	40	20	10
10	20	10	10	10	10	20	10
30	40	20	40	10	50	30	40
30	20	40	30	20	10	10	10
30	10	20	30	40	20	40	50
30	20	50	40	30	20	20	30
30	40	10	20	30	40	20	30
20	30	30	10	20	30	10	20
40	20	40	30	20	40	40	30
30	20	40	20	30	30	10	20
30	20	10	10	20	30	10	10
20	30	10	20	20	50	40	50
10	40	20	10	40	60	30	40
30	20	40	30	40	40	30	40
20	10	30	20	10	40	20	10
40	50	30	20	40	40	20	30
10	30	20	10	30	20	10	30
20	50	30	20	40	50	30	20
50	30	50	40	30	60	30	40
20	40	20	50	10	40	30	10
50	40	20	40	40	50	30	50
10	30	20	30	10	40	20	30
30	10	50	30	20	30	10	20
10	40	30	10	40	40	20	40
20	10	40	20	50	60	40	30
20	40	30	50	30	40	30	20
50	40	30	10	20	20	30	10
30	50	40	20	40	60	30	40
30	50	30	10	30	50	30	20
20	30	40	20	10	40	20	30
30	40	20	40	30	40	20	40
40	50	20	50	20	50	30	50
50	30	50	30	30	50	20	50
40	20	50	30	30	20	40	30
20	40	20	30	40	50	20	40
30	50	30	20	50	20	10	40
30	10	20	30	50	20	30	10
40	30	40	20	50	30	30	40

50	40	30	50	30	40	20	50
20	50	40	50	20	50	30	20
40	30	50	30	20	30	10	40
40	60	30	40	20	60	30	40
30	40	30	40	10	50	30	50
40	20	40	30	40	10	30	50
30	20	40	30	10	40	20	50
30	40	10	20	30	40	20	30
30	40	20	30	40	50	20	40
30	20	40	20	40	50	30	20
80	90	80	100	100	80	100	100
40	20	50	20	40	30	20	40
40	30	40	20	30	20	10	40
20	40	20	60	30	30	60	50
20	40	30	60	40	40	50	30
50	30	40	50	30	50	30	50
30	10	30	20	40	20	50	40
20	40	20	50	40	20	40	10
40	60	20	40	30	20	40	30
30	20	50	30	30	20	20	40
40	20	40	40	20	50	30	40
50	40	20	50	30	60	40	20
40	30	60	30	40	20	40	20
40	20	50	20	30	50	30	30
30	20	40	20	40	60	40	40
70	40	30	50	40	20	20	40
20	30	10	40	20	20	30	10
20	10	30	20	30	20	40	20
30	10	40	50	30	50	20	30
90	70	90	80	90	70	100	90
70	50	40	20	30	40	30	40
40	60	40	50	30	60	30	20
40	30	60	40	30	50	50	20
50	70	40	50	30	60	40	20
60	30	50	40	60	40	50	20
50	30	50	20	60	30	40	50
50	30	50	20	40	50	20	30
50	30	70	50	30	50	30	40
40	20	60	30	20	50	20	60
40	20	40	30	30	40	50	20
40	20	40	20	30	50	30	10

Appendix 10

Average percentages							
35	33	35	32	32	39	30	33

Appendix 11

Indices of sub indicators							
0.35	0.33	0.35	0.32	0.32	0.39	0.30	0.33

Appendix 12

Indices of main indicators							
0.041	0.039	0.041	0.038	0.038	0.046	0.035	0.039

Appendix 13

Average indices of main indicators
0.040

Appendix 14

percentages for individual sub indicators - navigation			
30	20	10	10
10	30	20	30
20	30	10	40
60	40	70	50
20	10	30	40
20	10	30	20
40	30	20	30
40	30	20	30
20	40	10	40
10	30	30	50
30	20	30	40
20	10	20	40
20	10	10	30
20	30	20	40
10	20	40	10
30	20	30	20
20	30	10	30
20	10	40	40
10	20	40	50
40	30	50	30
10	30	20	10
40	30	20	30

30	10	50	30
30	20	40	10
50	20	40	20
50	40	20	40
40	20	40	20
40	30	10	50
40	60	30	40
30	40	50	20
20	10	30	20
40	20	40	10
30	50	40	50
50	30	40	30
30	20	40	20
20	40	10	30
30	20	40	10
30	20	40	20
20	40	30	10
40	50	20	10
40	20	50	40
30	10	50	30
30	50	30	30
30	40	20	40
50	30	40	50
40	20	50	30
20	40	20	30
30	40	30	50
30	40	20	20
80	100	90	100
40	10	40	20
30	50	30	50
20	40	20	30
30	50	30	40
40	30	50	30
20	30	50	20
40	50	30	40
40	50	30	50
50	20	50	20
30	40	20	40
30	40	30	20
30	10	40	20
50	40	30	40
30	40	20	40
40	30	50	30
30	20	10	40

80	90	70	90
30	50	30	20
30	50	30	40
30	20	40	20
40	20	50	30
60	30	70	40
40	40	50	40
30	50	20	40
30	50	30	20
50	30	50	20
50	30	50	30
30	50	20	50
40	30	50	20
30	20	40	20

Appendix 15

Average percentages			
33	32	34	32

Appendix16

Indices of sub indicators			
0.33	0.32	0.34	0.32

Appendix17

Indices of main indicators			
0.043	0.041	0.044	0.041

Appendix 18

Average indices of main indicators
0.042

Appendix 19

percentages for individual sub indicators - Agriculture				
30	30	40	30	30
30	20	30	10	40
30	20	50	20	10
60	40	20	50	40
40	20	10	30	10
50	30	20	30	30
30	20	50	30	10
10	20	10	30	20
30	20	40	50	40
20	10	40	30	50
30	20	10	30	50
20	10	30	40	40
20	40	30	10	40
30	10	40	30	20
30	10	30	30	20
10	20	30	20	10
10	20	10	30	20
20	10	30	20	10
50	20	40	20	40
50	30	40	30	20
10	30	20	30	40
10	30	20	20	30
20	10	30	20	40
40	30	50	40	30
50	40	10	40	30
10	30	20	50	30
20	30	30	10	40
10	40	20	30	40
10	20	40	20	50
10	30	10	50	30
10	20	30	10	50
30	20	40	30	20
40	30	40	60	40
30	50	30	40	20
30	20	40	30	50
30	10	40	30	20
30	10	30	40	20
10	30	20	40	30
20	40	30	20	40
20	40	20	40	10
10	30	20	10	40

20	40	10	30	50
30	40	20	40	30
10	40	20	20	50
30	10	20	40	10
30	10	40	30	20
40	20	30	10	30
20	40	30	20	50
10	40	20	10	40
20	40	20	30	40
10	30	20	30	20
10	30	20	30	40
40	30	40	30	50
30	20	40	30	40
40	50	30	40	30
40	20	50	30	40
50	30	40	30	40
30	50	30	30	50
40	20	40	30	20
20	30	20	50	30
20	30	50	30	30
30	20	50	30	20
30	10	30	40	30
20	30	10	40	30
40	20	30	40	30
20	10	40	20	30
10	30	50	20	20
50	30	20	50	30
40	20	50	40	30
30	10	30	20	40
30	20	50	20	40
30	10	40	30	20
30	40	20	40	50
40	20	50	20	30
40	10	30	50	20
40	10	50	30	50
30	40	30	20	50
40	20	40	20	30
50	30	50	30	20
40	20	30	40	20

Appendix 20

Average percentages				
28	25	31	30	32

Appendix21

Indices of sub indicators				
0.28	0.25	0.31	0.30	0.32

Appendix22

Indices of main indicators				
0.035	0.031	0.038	0.038	0.040

Appendix 23

Average indices of main indicators
0.036

Appendix 24

percentages for individual sub indicators - Hydropower			
10	40	70	50
30	10	20	40
10	60	70	30
30	70	60	50
40	50	40	60
10	60	50	60
30	70	50	30
40	20	30	40
30	70	50	40
30	50	40	60
50	70	50	20
40	70	50	40
30	70	30	40
30	60	40	30
30	80	30	60
20	60	40	20
40	60	40	20
30	70	20	50
40	70	40	20
40	60	60	50
30	70	30	20
10	60	20	30
40	60	30	20
30	80	40	30
30	50	40	20
30	60	40	30

50	80	30	30
20	60	30	30
40	70	40	40
40	80	30	10
30	70	30	20
40	40	30	50
30	40	20	50
50	70	40	60
60	80	40	20
30	80	50	40
40	70	40	30
40	70	40	20
20	80	40	30
40	60	40	30
30	90	30	30
50	30	10	40
40	20	50	20
30	60	40	30
40	80	40	40
50	30	40	20
40	70	40	30
20	80	50	30
40	70	30	20
40	90	40	20
40	70	40	30
50	90	40	30
50	60	40	30
50	40	30	40
50	90	40	60
40	70	50	30
20	50	40	20
40	70	40	50
40	50	30	20
60	30	50	20
40	20	50	40
50	70	40	30
30	60	40	40
30	20	40	30
30	40	20	30
40	60	40	30
40	40	30	40
50	40	50	40
60	40	40	60
40	60	40	60

30	50	30	20
60	70	40	50
20	40	50	30
50	80	30	40
40	30	50	30
50	60	40	50
20	60	30	40
50	30	50	40
40	30	40	20
50	60	30	50

Appendix 25

Average percentages			
37	59	39	35

Appendix 26

Indices of sub indicators			
0.37	0.59	0.39	0.35

Appendix 27

Indices of main indicators			
0.046	0.073	0.049	0.043

Average indices of main indicators
0.053

Appendix 28

Appendix 29

percentages for individual sub indicators - Biological degradation						
20	20	30	40	10	20	30
20	10	30	40	30	20	50
10	10	20	30	50	10	40
40	10	20	40	50	50	20
20	10	40	30	20	30	10
40	20	40	20	40	20	10
30	20	40	50	30	20	50
10	40	30	10	30	20	40
20	30	50	30	20	50	10
20	40	30	30	40	20	40

30	50	50	30	10	30	50
10	20	20	10	30	20	10
20	30	10	40	50	30	20
30	40	50	40	30	20	40
30	20	30	40	30	50	20
30	20	30	10	30	20	20
30	20	40	20	30	10	30
20	30	40	10	20	10	40
10	40	30	20	30	50	30
30	50	40	50	20	40	30
10	20	30	10	30	20	10
20	10	40	20	30	30	10
20	10	20	40	20	30	20
50	20	40	30	20	30	50
30	30	20	40	10	20	50
30	20	40	10	50	10	30
40	20	50	30	50	20	40
20	40	20	50	30	20	60
20	20	40	30	40	30	20
40	30	50	20	10	40	20
30	10	40	10	20	40	10
30	50	30	20	40	10	60
30	50	50	40	50	30	60
20	50	30	20	30	10	40
40	20	50	20	60	30	40
20	40	10	30	30	40	20
30	40	20	40	60	30	40
40	20	30	10	40	50	20
30	20	40	10	50	20	10
30	50	30	40	20	10	40
50	20	40	20	10	50	30
40	20	50	30	10	50	30
20	40	20	40	30	40	20
40	20	30	10	40	20	30
20	30	10	50	20	30	10
30	20	40	20	30	40	30
40	20	30	40	20	40	30
40	30	50	30	50	20	40
40	20	40	50	30	20	40
30	20	40	30	60	20	40
40	20	30	50	40	10	40
40	50	40	30	50	30	50
20	40	20	30	40	50	30
30	50	30	50	40	40	50

50	40	50	60	30	40	50
30	20	50	30	40	50	30
40	20	50	40	20	40	50
30	10	40	20	40	20	50
30	20	50	30	20	30	40
30	40	20	40	30	30	40
20	40	30	20	40	20	30
30	40	20	30	20	30	50
40	20	40	30	50	40	30
40	30	40	20	30	40	30
40	20	30	40	20	30	40
20	40	20	50	30	20	30
30	20	40	20	30	10	40
50	20	40	30	20	50	30
30	20	40	30	50	20	50
30	20	40	20	40	20	60
40	30	20	30	50	30	40
30	50	30	50	30	20	50
30	20	50	30	20	50	30
20	40	10	40	30	40	60
40	50	30	50	30	20	30
20	40	20	50	30	50	50
50	20	50	20	40	30	50
20	40	30	50	20	50	30
30	10	40	20	40	20	40
30	50	20	40	30	20	40

Appendix 30

Average percentages						
30	28	34	31	32	29	35

Appendix 31

Indices of sub indicators						
0.30	0.28	0.34	0.31	0.32	0.29	0.35

Appendix 32

Indices of main indicators						
0.036	0.034	0.041	0.038	0.039	0.035	0.042

Appendix 33

Average indices of main indicators
0.038

Appendix 34

percentages for individual sub indicators - Urbanization and infrastruction development	
40	30
50	10
40	50
60	40
50	60
40	20
50	20
40	20
20	40
60	40
50	60
30	10
40	50
40	20
50	60
30	20
40	20
40	30
60	40
60	50
30	20
60	70
60	40
50	60
20	40
40	30
60	70
60	50
20	20
60	50
50	20
60	50
50	70
80	70
80	40
50	40
60	40
70	30
70	30

40	20
70	50
70	30
40	20
40	20
30	10
60	20
60	40
60	30
60	30
40	20
50	10
60	20
80	30
70	20
80	50
60	20
60	40
50	30
40	30
70	30
50	30
40	20
60	40
40	40
50	20
40	60
30	40
60	50
70	40
50	70
50	20
70	30
40	50
70	40
50	10
30	40
50	20
60	30
50	10
60	40

Appendix 35	
Average percentages	
52	35

Appendix 36

Indices of sub indicators	
0.52	0.35

Appendix 37

Indices of main indicators	
0.065	0.044

Appendix 38

Average indices of main indicators
0.054

Appendix 39

percentages for individual sub indicators - Natural causes						
50	50	30	30	40	50	50
50	50	50	30	20	50	60
50	40	40	20	30	50	30
50	50	40	20	20	60	60
30	40	30	20	30	50	40
50	60	40	30	40	70	50
40	50	40	20	10	50	30
60	40	30	20	30	50	50
30	40	30	20	20	50	30
60	50	40	20	10	50	40
50	40	60	50	50	60	70
30	20	20	30	10	60	40
40	30	50	30	30	70	50
40	60	50	40	30	60	50
40	30	20	40	10	50	50
30	40	40	10	20	50	30
50	40	20	30	10	60	30
40	30	20	30	20	50	20
30	40	20	20	30	50	20

30	10	30	20	10	50	30
30	30	10	20	10	20	30
40	20	10	10	20	40	10
20	40	10	30	20	50	20
30	50	20	30	20	50	20
20	40	20	30	10	40	20
50	30	40	30	20	50	40
30	20	10	30	10	40	30
30	20	50	30	10	40	10
40	30	30	40	20	50	20
40	50	30	20	40	60	40
10	40	30	20	10	50	20
20	40	20	10	10	40	20
40	30	60	40	20	60	40
40	30	50	20	10	80	40
50	40	70	50	30	50	10
40	60	30	40	20	50	20
40	50	40	20	10	50	60
60	40	30	50	40	60	40
40	20	30	10	10	40	20
40	10	20	50	20	60	30
20	50	30	10	10	30	10
30	40	20	50	20	40	50
30	50	30	40	20	50	40
30	50	30	40	50	50	30
40	20	30	10	20	50	60
30	40	20	20	30	50	30
30	50	30	20	10	50	30
40	20	40	20	10	50	20
30	40	40	50	20	50	40
40	30	50	30	10	40	50
30	20	40	20	10	40	30
30	20	50	30	10	50	30
40	30	40	20	20	60	40
30	50	30	40	30	50	30
40	20	50	40	30	50	60
40	30	50	40	20	60	40
40	60	30	40	30	50	30
60	30	50	20	30	50	40
30	40	20	30	40	60	30
40	20	50	30	10	30	40
50	20	30	40	20	40	20
40	20	50	30	20	50	30
30	40	20	40	20	40	30

20	40	20	30	50	30	50
30	40	20	40	20	50	20
20	40	30	30	30	20	40
20	10	40	40	20	40	30
50	30	60	40	30	70	40
50	30	60	40	20	40	30
30	40	30	40	20	30	30
30	50	30	10	20	50	40
40	50	30	60	20	60	30
30	20	50	30	10	60	30
40	30	50	30	40	50	30
40	30	50	30	20	30	40
50	30	50	30	20	50	30
40	30	50	20	30	50	20
30	50	40	20	30	50	30
30	40	20	40	50	80	30
30	40	30	20	30	50	20

Appendix40

Average percentages						
37	36	35	30	22	50	34

Appendix41

Indices of sub indicators						
0.37	0.36	0.35	0.30	0.22	0.50	0.34

Appendix42

Indices of main indicators						
0.046	0.045	0.043	0.037	0.028	0.062	0.042

Appendix 43

Average indices of main indicators
0.043

Appendix 44

percentages for individual sub indicators - Water quality			
30	30	20	30
10	20	30	20
10	20	10	40
10	40	20	40
20	40	30	20
10	20	30	20
10	20	40	20
10	30	20	40
30	20	50	30
10	30	20	30
40	50	50	40
10	10	40	20
20	40	30	40
20	30	40	20
10	30	40	10
20	30	30	40
20	40	20	10
30	20	50	30
40	30	50	40
10	40	30	10
10	30	20	10
10	30	20	20
20	40	20	40
20	40	10	30
10	30	20	50
20	40	20	10
10	40	30	50
10	30	20	50
20	50	30	10
10	50	30	40
10	30	20	40
40	30	20	50
20	40	20	40
30	60	40	30
40	30	60	50
30	20	50	30
10	40	30	10
20	10	40	20
20	40	30	10
20	40	50	30
40	30	10	40

30	10	30	50
20	10	50	20
10	30	20	10
10	20	40	20
20	40	30	30
30	20	50	10
10	40	30	20
10	20	40	20
10	30	20	40
10	40	20	10
30	20	50	20
40	30	60	50
30	20	50	40
20	40	20	50
10	30	20	10
40	20	60	40
20	50	30	20
10	30	20	40
20	30	20	30
30	10	20	30
20	40	20	10
20	30	40	20
10	30	10	40
20	30	10	30
20	10	40	20
10	30	20	10
30	10	60	30
20	40	20	30
30	10	40	20
40	20	50	30
20	50	20	10
20	50	30	20
30	50	20	40
20	40	20	10
40	30	60	30
30	40	50	20
30	50	30	40
30	50	20	50
30	20	40	30

Appendix45

Average percentages			
21	31	32	28

Appendix46

Indices of sub indicators			
0.21	0.31	0.32	0.28

Appendix47

Indices of main indicators			
0.028	0.043	0.043	0.038

Appendix 48

Average indices of main indicators
0.038

QUESTIONS RESPONSES 80

Section 1 of 10

Indian Institute of Technology, Department of Water Resources Development and Management, Roorkee

Illegal small-scale mining popularly referred to in Ghana as 'Galamsey' has been rampant for decades. Although Artisanal and Small-Scale Gold Mining (ASGM) offers economic benefits and employment opportunities to about 4.5% of the Ghanaian populace, its impact on human health has led to a high incidence of health hazards, deforestation, pollution and loss of biodiversity.
This research is being carried out on the topic above and the questionnaire is designed to gathered information on site suitability and land evaluation of the basin under the main criteria of hydropower, land use changes, navigation, automation water quality and future land use map.
Your input will be favourably acknowledge and any further questions, please contact me on this e-mail benjaminlawortey@gmail.com

1. Title

1. Mr.
2. Mrs.
3. Ms
4. Engineer
5. Dr.
6. Prof

2. Name

Short answer text

3. Organisation (optional)

Short answer text

4. Designation (optional)

Short answer text

5. Contact number (optional)

Short answer text

Section I

In your opinion, how important (on a scale of 1 - 10) are the indicator for revitalization and development criteria ie, mining, navigation, agriculture, hydropower, biological degradation, urbanization and infrastructure development, natural causes and water quality

6. Mining (illegal)

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

7. Navigation

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

8. Agriculture

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

9. Hydropower

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

10. Biological degradation

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

11. Urbanization and infrastructure development

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

12. Natural causes

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

13. Water quality

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

Section 2 of 10

Section II

In your opinion, how important (on a scale of 1-10) are the mining sub indicator (1=minimum and 10=maximum)

14. poverty

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

15. Industry

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

16. Waste deposition

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

17. Hazardous chemical

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

18. Surface water

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

19. Population pressure

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

20. Erosion

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

21. Reclamation

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

After section 2 **Continue to next section**

Section 3 of 10

Section III

In your opinion, how important (on a scale of 1-10) are the navigation sub indicator (1=minimum and 10=maximum)

22. Changes in river morphology

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

23. Natural causes

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

24. Industrial activities and mining

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

25. Natural biodiversity

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

After section 3 **Continue to next section**

Section 4 of 10

Section IV

Section 4 of 10

Section IV

In your opinion, how important (on a scale of 1-10) are the agriculture sub indicator (1=minimum and 10=maximum)

26. Poverty

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

27. Overgrazing

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

28. Exploitation of vegetation

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

29. Reduction of plant cover and residues

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

30. Inappropriate application of manure, fertilizer, herbicides, pesticides and agro-chemical

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

After section 4 **Continue to next section**

Section 5 of 10

Section v

In your opinion, how important (on a scale of 1-10) are the hydropower sub indicator (1=minimum and 10=maximum)

31. Sediment prevention and control

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

32. Power potential

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

33. Seasonality of the Ankobra river basin

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

34. Social impact management

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

After section 5 **Continue to next section**

Section 6 of 10

Section VI

In your opinion, how important (on a scale of 1-10) are the biological degradation sub indicator (1=minimum and 10=maximum)

35. Vegetation cover

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

36. Loss of habitat

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

37. Biomass

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

38. Detrimental effect of fires

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

39. Quality and species composition/diversity

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

40. Loss of soil life

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

41. Afforestation and forest protection

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

After section 6 **Continue to next section**

Section 7 of 10

Section VII

In your opinion, how important (on a scale of 1-10) are the urbanization and infrastructure development sub indicator (1=minimum and 10=maximum)

42. Settlement and roads

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

43. (Urban) recreation

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

After section 7 **Continue to next section**

Section 8 of 10

Section VIII

In your opinion, how important (on a scale of 1-10) are the natural causes sub indicator (1=minimum and 10=maximum)

44. Change in temperature

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

45. Change in seasonal rainfall

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

46. Heavy/ extreme rainfall (intensity and amounts).

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

47. Windstorms/ dust storms

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

48. Flood

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

49. Droughts

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

50. Topography

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

After section 8 **Continue to next section**

Section 9 of 10

Section IX

In your opinion, how important (on a scale of 1-10) are the water quality sub indicator (1=minimum and 10=maximum)

51. Water quality

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

52. Sand dune stabilization

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

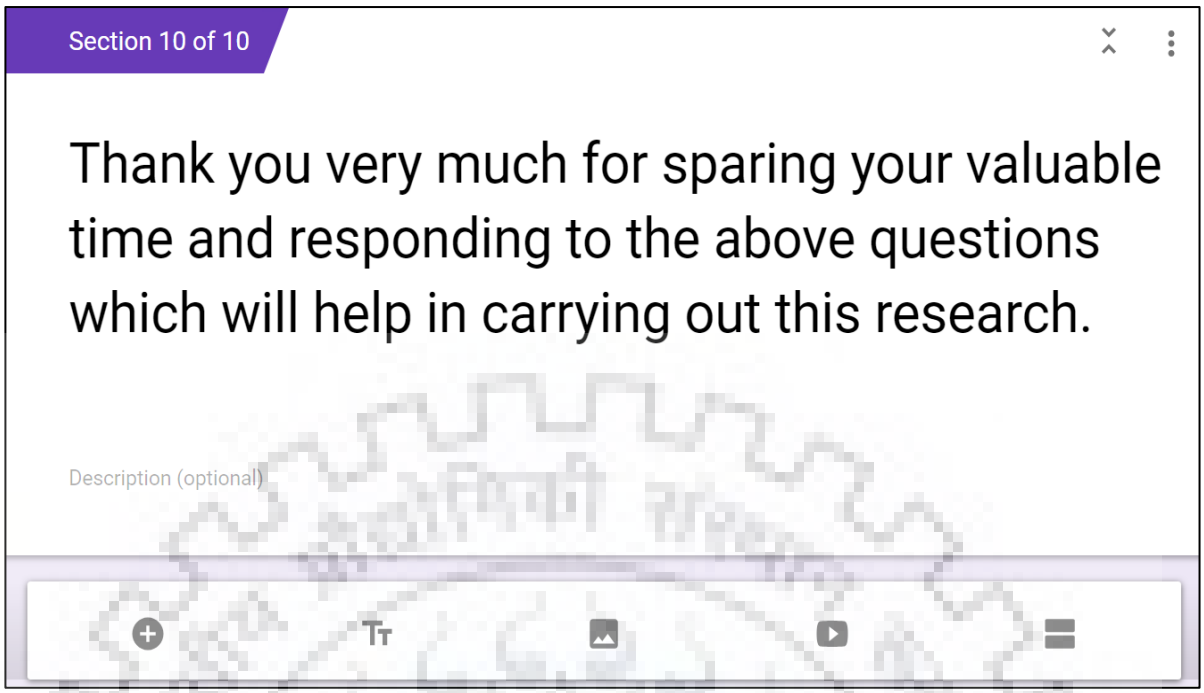
53. Protection against natural hazards

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

54. Water flow quantity

	1	2	3	4	5	6	7	8	9	10	
minimum	○	○	○	○	○	○	○	○	○	○	maximum

After section 9 **Continue to next section**


Section 10 of 10
Thank you very much for sparing your valuable time and responding to the above questions which will help in carrying out this research.
Description (optional)