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Integrated Assessment of Land and Water Resources Potentials towards Surface Irrigation Systems Development in Upper Ogun River Basin, Nigeria

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Abstract

Global warming with resultant gross rainfall unreliability and variability negatively impacts agricultural production thus constituting serious threat to sustainable food production systems. To address this problem, there is great need for a sustainable irrigated agricultural development based on an integrated assessment of land and water resources to ensure optimal utilization. An integrated evaluation of the land and water resources of the upper Ogun River Basin was embarked on to identify suitable lands, based on mitigating factors such as terrain relief, soil physical properties, land cover/use, river proximity, road accessibility, farm settlement and markets locations, and to quantify the volume of accessible surface water to drive irrigated agricultural development. The methodology involves the utilization of georeferenced remotely sensed datasets (10m Sentinel-2 imagery, 12.5m ASTER GDEM, spatially interpolated climate and soil data on grids, etc.) and the employment of geo-statistical and geo-visualization capabilities of GIS tools (Sentinel SNAP, ENVI5.3, Google Earth Pro, ArcGIS 10.8 and HEC-HMS 4.7.1) for image processing and accuracy assessment, land cover characterisation, watershed delineation, soil suitability evaluation, hydrological simulation, etc., to *generate the final products. Analytical Hierarchical Process was the fundamental scale for pair wise comparison matrix of the elements used for surface irrigation suitability evaluation. The results revealed that approximately 704.9 square kilometres (9%) of the total land area is suitable for immediate irrigated agricultural development while the total volume of surface water accessible was quantified as 11,194,205,087.223 cubic metre. This baseline information provides an important guide at the conception of an irrigated agricultural development project.*

Introduction

At the base of the Maslow's hierarchy of needs is the physiological class, the basic needs for physical survival which include food, water, a liveable environment, clothing and shelter. Those needs, food especially, are very fundamental to continuous human existence thus deserve serious consideration. Ensuring sustainable food production systems and implementing resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality are some of the targets of goal number 2 of the United Nations' (UN) Sustainable Development Goals (SDGs) (UNDP, 2015). These are imperative in view of the high degree of rainfall variability and unreliability of recent years occasioned by the impact of the global climate change due to which crop failures have now become recurring decimals. As the main component that drives growth of all kinds of agricultural produce, availability of adequate water resource at the point of need is undeniably integral to any agricultural development plan. Obviously, water resources utilization through irrigated agriculture provide supplementary and full season irrigation thus overcoming the effects of rainfall variability and unreliability. Hence, food insecurity could be eradicated through irrigation development that reduces variation in harvest and intensify cropping through production of multiple crop annually.

Sustainable food production anticipated through an optimal development of water resources, in conjunction with development of land depends on the method of irrigation considered (FAO, 2003). These methods are broadly classified into three categories: surface (basin, border, and furrows), sprinkler, and drip/micro-irrigation methods. Surface irrigation is the application of water by gravity flow to the surface of the field, either the entire field is flooded (basin irrigation) or the water is fed into small channel (furrow) or strip of land (borders). It is the oldest and still the most widely used method of water application to agricultural lands. Surface irrigation have inherent benefits for the less skilled rural farmers. In the first instance, findings revealed that more than 90% of the world irrigated agriculture systems are surface irrigation based, with limited knowledge and technicality required of local irrigators to operate and maintain the system (Saymen, 2005). In addition, these systems can be developed at the farm level with minimal capital investment. The main capital investment in surface system is mainly associated with landscaping. If the terrain is not too undulating, these costs are reduced. Therefore, surface irrigation development requires favorable topography and information on land and water resources for proper planning (FAO, 1995). In essence, planning process for surface irrigation has to integrate information about the suitability of the land, water resources availability and water requirements of irrigable areas in time and place (FAO, 1997).

Generally, rural lands have varying terrain configurations, soil forms, and land cover/use types. In order to determine the suitability of land for surface irrigation, a thorough evaluation of soil properties, relief (slope) of the land within field (Fasina *et al*, 2008) and locating areas of land covers/uses most suitable for irrigation and to which water can be supplied (FAO, 1993) is required. The volume of water accessible for irrigation is determined through hydrological studies of surface water (FAO, 1985). Once the amount of river discharges is quantified, an important part of the evaluation is the matching of water supplies and water demand (FAO, 1977). Irrigation water supply and demand are therefore significant factors in irrigation potential assessment. Essentially, these factors have to be assessed in an integrated manner, georeferenced and mapped for surface irrigation development possibilities. With accessibility to a spatial database, Geographic Information Systems (GIS) serves a powerful analytic and decision-making tool for irrigation development (Aguilar-Manjarrez & Ross, 1995). GIS' ability to collect, store, retrieve, update and manipulate various types of data in a unique spatial database aids performing various kinds of analysis thus, extracting information about spatially distributed phenomena. In this case, relevant factors to irrigation potential assessment such as soil, land cover/use, terrain configuration and distance between water supply and suitable command area are to be weighted and evaluated with GIS to determine target lands suitability for irrigation.

Basic Concepts of the Research

Irrigation Development Potential

Irrigation is an intentional human activity of applying controlled amounts of water to soil to assist in growing crops, especially during dry seasons when there is a shortage of rainfall. It is a practice, an artificial process of applying additional water, beyond what is available from rainfall, to soil for the purpose of supplying essential moisture in the plant root-zone to prevent stress thus enabling or enhancing plant growth and yield, and, in some cases, the quantity of foliage or harvested plant parts (Sojka *et al*, 2002; Reddy, 2010). Scholars have identified the relevance of irrigation in a wide arrays of agricultural crop production to include frost protection, suppressing weed growth in grain fields and preventing soil consolidation (Snyder

& Melo-Abreu, 2005; Williams *et al*, 2007) as well as other endeavors such as maintaining landscapes, revegetating dried lands, cooling livestock, dust suppression, disposal of sewage, and in mining.

Irrigation is often studied together with *drainage*, which is the natural or artificial process of removal of surface and sub-surface water from a given location. The configuration of terrain oftentimes without the intrusion of human activities is usually such that surface waters are collected from elevated surfaces and drained through lowland canals into streams and rivers channels which will ultimately discharge such waters into the ocean. This natural arrangement is the determinant for collection and storage of surface water which can be utilized for a variety of purposes including irrigation. Thus a very efficient system of irrigation development will give credence to existing natural drainage networks and likely inculcation of artificial ones to boost functionality of such networks.

Irrigation potential implies a variety of assumptions related to irrigation techniques, investment capacity, social, health and environmental concerns, national and regional policies, and international relationships, notably regarding the exploitation of shared water resources. Efficient assessment of land and water resources at river basin level requires adequate knowledge of the physical irrigation potential. *Physical irrigation potential* represents a combination of information on gross irrigation water requirements, area of soils suitable for irrigation and available water resources by basin. Potential areas which can be irrigated depend on the basic physical resources *land* and *water*, combined with the water requirements for irrigation as determined by the cropping patterns and climate (FAO, 1997).

Irrigation practice in Nigeria started from way back in history, however its current modalities and popularity can be attributed to a study which was carried out in 1972 to examine the country’s water resources and irrigation development potential. That study led to the institution of three models public irrigation schemes; namely the Bakolori scheme, the Chad Basin scheme, and Kano River irrigation scheme (NINCID, 2015). Subsequently, additional eleven more River Basin Development Authorities (RBDAs) were added across the country after the success of the pilot schemes in 1976. These RBDAs include the Niger Basin; Lower Benue Basin, Upper Benue Basin, Lake Chad Basin, Benin- Owena Basin, Sokoto Rima Basin, Hadejia Jama’are Basin, Cross River Basin, Ogun-Osun Basin, Anambra-Imo Basin, and Niger Delta Basin. Through the RBRDAs, about 162 dams with 11 billion m3 reservoir capacity were constructed, with the intention to irrigate about 725,000 ha. For efficiency and sustainability of these large-scale public irrigation schemes to provide food sufficiency, one basic requirement is a comprehensive study of the covered areas for optimal deployment of resources. The National Irrigation and Drainage Policy and Strategy (NIDPS) classified irrigation schemes and projects in Nigeria into three categories; the public irrigation schemes, which are government-executed schemes, the farmer-owned irrigation scheme, and the floodplains called Fadama irrigation scheme. Nigeria's total water demand for the year 2010 was put at 5,933 Million Cubic Meters per year (MCM/year) while by the year 2030, it is estimated to rise to 16,585 MCM/year. The water use rate (the ratio between the total water demand and the water resources potential) in 2010 was just 1.6% and is expected to grow to 4.4% by the year 2030. Thus, the total water demand is much less than the total water resources potential. However, because the water demand and water resources are unevenly distributed, the necessity of surface water and groundwater resources development should be examined through the water balance between supply and demand at local levels (FMWR, 2015).

Table 1. Irrigation projects supported by Dams/Intake works constructed by River Basin Development Authorities in Nigeria (Source: Okeke & Ofulume, 1997)

Name of Irrigation projects	Size of Irrigation Projects (ha)	Name of dams/Intake Works Support Irr.		Type of Length of dam dem (m)	Location of dam (State)	Reservoir Capacity (MCM)	Purpose	Owner
Bakolori I. P	23000	Bakolori	C	5491	Sokoto	450	Irri.	SRBDA
Rima River I. P	33000	Goronyo	E	7210	Sokoto	974	Irri.	SRBDA
Kano River I. P	14000	Tiga	E	6000	Kano	1968	Irri.	HJRBDA
Dadinkowa I. P	44000	Dadinkowa	R	9000	Gombe	2765	Irri-WS	UBRBDA
Lower Ogun I. P	12500	Ogun	E	1044	Ogun	270	Irri WS, F	OORBDA
Middle Ogun I. P	12500	Ikere-Gorge	R	600	Oyo	565	Irri WS F	OORBDA
Swashi I. P	5300	Swashi	E	600	Kwara	5	Irri.	NREBDA
Kiri. P	6000	Kirota	E	1025	Adamawa	325	Irri	UBRBDA
Hadejia Valley I. P	12500	Galala	E	726	Kano	24	Irri.	HJRBDA
Jibiya I. P	3400	Jibiya	E	3170	Kaduna	121	Irri.	NRBDA
Zobe I. P	6000	Zobe	Na	2750	Kaduna	177	Irri.	NRBDA
Kampe I. P	6000	Ogin	E	750	Kwara	750	Irri.	NRBDA
Erini 1. P	4036	Oni	E	1976	Kwara	1600	Irri.	NRBDA
Lower Anamb. I. P	4200	Ifite Intake Wks		-	Anambra	103/5	Irri.	AIRBDA
South Chad I. P	60000	South Chad Intake Wks		-	Borno	na	Irri.	CBDA
	248,436							

Legend: C = Concrete dam, E = Earthfill dam, R = Rockfill dam, ha – hectares, MCM = Million Cubic Metre.
CBDA = Chad Basin D. A, AIRBDA = Anambra/Imo RBDA, SRBDA = Sokoto BDA, HJRBDA = Hadejia/Jamare RBDA
UBRBDA = Upper Benue RBDA, OORBDA = Ogun/Ohun RBDA, NRBDA = Niger River BDA, Irri, = Irrigation.
WS = Water Supply, F = Fishery.

Irrigation Land Suitability Evaluation

Land suitability is the fitness of a given land for a defined use. Land may be classified in its present condition or after improvements have been effected for a specific use. Primarily, land evaluation is the analysis of land related data (e.g. climate, soils, vegetation, etc.) in terms of realistic alternatives to improve their use. Land Evaluation demands a comparative analysis of the required inputs and accrued benefits on different types of land. For irrigation land suitability analysis, particular attention is given to the physical properties of soil, proximity to available water sources and terrain conditions relative to methods of irrigation considered (FAO, 2007). Additionally, land cover/use types are considered as limiting factors in land suitability evaluation for irrigation (Haile Gebrie, 2007; Meron, 2007). As exhaustively discussed in FAO land evaluation guidelines (FAO, 1976, 1983, 1985), the suitability of these factors for surface irrigation method and for the given land utilization types can be expressed corresponding to suitability classes:

Order S - Suitability Classification

The classes under this order are:

a. S1 (highly suitable) - land having no significant limitation to sustained application of a given use.

b. S2 (moderately suitable) - land having limitation which in aggregate are moderately severe for a sustained application of a given use.
c. S3 (marginally suitable) - land having limitation which in aggregate are severe for a sustained application o1f a given use and will reduce productivity or benefits.

Order N - Suitability Classification

The classes under this order are:

a. N1 (temporarily not suitable) - land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost.
b. N2 (Permanently not suitable) - land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land of a given land use.

The main factors considered for surface irrigation suitability evaluation are water availability, relief, soil physical qualities and land cover/use types. Quantifying the amount of water available and timing for irrigation as well as determining the exact locations to which water can be economically transported are important factors in evaluating land suitability for irrigation. According to FAO standard guidelines for the evaluation of slope gradient, slopes which are less than 2%, are very suitable for surface irrigation. But slopes, which are greater than 8%, are not generally recommended (FAO, 1999). The assessment of soils for irrigation involves using properties that are permanent in nature that cannot be changed or modified. Such properties include drainage, texture, depth, salinity, and alkalinity (Fasina *et al*, 2008). Matching of existing land cover/use with topographic and soil characteristics to evaluate land suitability for irrigation with land suitability classes, present possible lands for agricultural production (Jaruntorn, *et al*, 2004*).*

Irrigation Water Resources Assessment

Assessment of water resources is best done at basin level (FAO, 1997). According to the Comprehensive Assessment of water management for agriculture (CA) (2007), "river basins are the geographic area contained within the watershed limits of a system of streams and rivers converging toward the same terminus, generally the sea or sometimes an inland water body. Tributary sub-basins or basins more limited in size (typically from tens of square kilometers to 1,000 square kilometers) are often called watersheds (in American English), while catchment is frequently used in British English as a synonym for river basins, watershed being more narrowly defined as the line separating two river basins.

An important consideration in water resource assessment is to estimate how much flow is available at the outlet of river catchment. The volume of water reliably available on an annual or seasonal basis can be determined from the available data in case of gauged rivers and for completely ungauged rivers the runoff coefficient method can be employed (Goldsmith, 2000). According to Department for International Development (DFID) (2004), when this is the case, then data from the gauging site should be used to estimate mean annual runoff (MAR) at ungauged site, provided that the requirements set out below are met:

i. Catchment characteristics should be similar;
ii. The distance between the centroids of the catchments should be less than 50 km;
iii. At least ten years of mean monthly flows should be available.

Otherwise, the simplest method of estimating mean annual runoff in ungauged site was established in applying a runoff coefficient to the mean annual rainfall as shown below in the following steps.

a. Determine the mean annual runoff (mm) at the gauged site as

$$MARg = K * MAP$$

(eqn. 1)

Where: *MARg* = Mean annual runoff at gauged site (mm)
MAP = Mean annual precipitation at gauged site (mm)

$$K = \frac{MARg}{MAP}$$

(eqn. 2)

Where: *K* = Runoff coefficient at gauged site

b. Determine the *MAR* at ungauged site as

$$MARu = K * MAPg$$

(eqn. 3)

Where: *MARu* = Mean annual runoff at un-gauged site (mm)

The mean annual or monthly runoff depth obtained from equitation (3) at un-gauged site can be converted to mean monthly runoff considering, average areal monthly rainfall and catchment area of both gauged and ungauged sites (Jamshid, 2003). Estimation of areal rainfall over a given catchment is therefore, useful for estimating the total runoff generated from the entire catchment. There are several methods of determining the spatial distribution of rainfall, and all of them yield slightly different variations of rainfall patterns across an area. The Thiessen method is a widely recognized scheme proven to be reasonably accurate for estimating areal precipitation distributions. The primary assumption in the Thiessen method is that areas closest to a precipitation station are most likely to experience similar rainfall conditions to those measured at the station location (Chow *et al*., 1988). Thiessen polygons can be constructed using the GIS to determine the spatial distribution of storms for computation of spatially variable excess rainfall. Grids of rainfall can also be computed and mapped for selected storm events (Melesse, 2002).

Review of Remote Sensing and Geographic Information System Applications

Remote Sensing (RS) refers to the technique of obtaining information about an object or feature through the analysis of data acquired by a device that is not in contact with the object or feature under investigation (Lillesand & Kiefer, 1994). *RS* as a technology has close ties to the *Geographic information System* (GIS). A *GIS* is computer software used for capturing, storing, querying, analyzing, and displaying geographically referenced data (Goodchild, 2000). Geographically referenced data are data that describe both the locations and characteristics of spatial features such as roads, land parcels, and vegetation on the Earth's surface. *RS* can provide timely data at scales appropriate to a variety of applications and the ability of a *GIS* to handle and process geographically referenced data distinguishes *GIS* from other information systems. It also establishes *GIS* as a technology important to a wide variety of applications, thus many researchers agreed that GIS and RS utilization can lead to important advances in research and operational applications. *RS* in combination with *GIS* is a powerful tool to integrate and interpret real word situation in most realistic and transparent way. Land cover/use mapping is one of the most important and typical applications of remote sensing (Lillesand & Kiefer, 2000). Land cover corresponds to the physical condition of the ground surface, for example, forest, grassland, concrete pavement etc. Land use reflects human activities such as the use of the land, for example, industrial zones, residential zones, agricultural fields etc.

For reflected electromagnetic radiation to convey meaningful information about the terrain represented, they are made to undergo several processes which aim to eradicate present irregularities in the images recorded by the sensors. This is called *Digital Image Processing (DIP)* which is the process of creating thematic maps from satellite imagery. A *thematic map* is an information representation of an image that shows the spatial distribution of particular theme (Lillesand & Kiefer, 2000). *Image preprocessing* allows the raw data received from imaging sensors mounted on satellite platforms, in other words called remotely sensed data which generally could contain flaws, deficiencies or errors due to the perspective of the sensor optics, the motion of the scanning system, the motion of the platform (altitude and velocity), the terrain relief or the curvature and rotation of the Earth to be corrected. Some of the errors might be radiometric distortions, geometric distortion and noise. So, before using the data for specific analysis, the data needs to be checked for likely effect of errors which must be removed. Such errors are corrected by using preprocessing techniques like radiometric correction, geometric correction and noise removal, applied on the raw image (Lillesand & Kiefer 2000).

Image Enhancement is used to increase the details of the image by assigning maximum and minimum brightness values to maximum and minimum display values, and it is done on pixel values. This makes visual interpretation easier and assists the human analyst. The visual interpretability of images is enhanced by using histogram equalization stretch (Lillesand & Kiefer, 2000) According Lillesand and Kiefer (2000), there are two main spectrally oriented classification procedures for land cover mapping which are unsupervised and supervised classification.

Unsupervised classification is more computer-automated. It enables user to satisfy some parameters that the computer uses to uncover statically patterns that are inherent in the data. These patterns are simply clusters of pixels with similar spectral characteristics. In some cases, it may be more important to identify group of pixels with similar spectral characteristics than it is to sort pixels into recognizable categories.

In *supervised classification* the image analyst supervises the pixel categorization process by specifying, to the computer algorithm, numerical descriptors of the various land cover types present in a scene. To do this, representative sample sites of known cover type, called training areas are used to create the parametric signatures of each class. Each pixel in the data set is then compared numerically to each category in the interpretation key and labeled with the name of the category it looks most like.

The main application in GIS is *mapping* where things are and editing tasks as well as for map based query and analysis (Campbell, 1984). A map is the most common view for users to work with geographic information. It is the primary application in any GIS to work with geographic information. The map represents geographic information as a collection of layers and other elements in a map view. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text, and a symbol legend.

A *watershed* can be defined as the catchment area or a drainage basin that drains into a common outlet. Simply, watershed of a particular outlet is defined as an area, which collects the rainwater and drains through gullies, to a single outlet. *Delineation* of a watershed means determining the boundary of the watershed i.e. ridgeline. GIS uses DEMs data as input to delineate watersheds with integration of Arc SWAT or by hydrology tool in Arc GIS spatial analysis (Winchell *et al*., 2008).

Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Geographic problems often require the analysis of many different factors using GIS. For instance, finding optimal site for irrigation requires weighting of factors such as land cover, slope, soil and distance from water supply (Yang Yi, 2003). To prioritize the influence of these factor values, weighted overlay analysis uses evaluation scale from 1 to 9 by 1. For example, a value of 1 represents the least suitable factor in evaluation while, a value of 9 represents the most suitable factor in evaluation. Weighted overlay only accepts integer raster as input, such as a raster of land cover/use, soil types, slope, and Euclidean distance output to find suitable land for irrigation (Janssen & Rietveld, 1990). Euclidean distance is the straight-line from the center of the source cell to the center of each of the surrounding cells.

Statement of the Problem

The adverse global warming effect combined with rapid population growth, declining land holding size, growing landlessness, environmental degradation, subsistence and rain-fed dependent agricultural production have resulted in a growing problem of food insecurity and price hike in the country. A number of previous studies (Adeola & Adetunbi, 2015; Akinbile *et al.,* 2016; Adelodun & Choi, 2018; Oluwatusin, *et al.*, 2020) have indicated that Nigeria has a large potential of irrigable agricultural land. The total surface area of Nigeria is estimated to be approximately 94,185,000 hectares. Out of this, cultivated area is currently estimated at 40.5 million hectares of land. Currently, high estimates show that about 3.4 million hectares of farmland could be potentially developed by irrigation. Nevertheless, a total area of 218,000 hectares out of 331,000 hectares equipped for irrigation is actually irrigated, including the area under traditional irrigation. However, the total estimated irrigable land potential in Nigeria is 2.3 million hectares assuming use of existing technologies. Irrigated agriculture has realized only 9.5% of its estimated potential indicating that a considerable cultivated land in Nigeria is currently not irrigated.

Recently, the agriculture sector has received a particular emphasis to transition towards a more comprehensive agricultural production system. Massive adoption of irrigation could substantially transform the agricultural sector, which at the moment is dominated by rain fed systems (Adelodun & Choi, 2018). As Nigeria attempts to exploit its river basin irrigation potential and develop strong water resources management techniques, there is a gap on concise and dynamic potential surface water irrigation management at the river basin level. Better understanding of the river basin characteristics is necessary in Ogun-Osun River Basin (Raphael *et al*, 2016), which is possible with knowing full potential of the available water and land resources thus predicting its total surface water irrigation potential. Any attempt to increase irrigation practice in the study area must take cognizance of changing land use practices, population growth, and climate change variability, all of which are significant problems to surface water irrigation systems. Those peculiar problems form the core of this study which aims to assess the availability of water resources and suitability of land resources towards a comprehensive irrigation system establishment.

Efforts to establish small and large-scale irrigation schemes in the region are constrained by a number of uncertainties. Firstly, stream flows from some of the rivers are not known. Secondly, potential irrigable areas in the region have not been identified and matched with the water requirements of common crops [a variety of both food and cash crops including cashew, cassava, cocoa, kolanut, maize (corn), melon, millet, oil palm, plantains, rice, rubber, sorghum, soybeans, bananas and yams] grown in the region. To overcome these uncertainties, this study adopts GIS as a tool for assessing irrigation potential of Upper Ogun Basin using input soil, climate and topographic data, digital elevation model (DEM), and satellite image (Landsat). Attempt was made to map irrigable lands and estimate surface water resource potential of the river main catchment and sub-catchments as well as the irrigation water requirements of the identified irrigable areas for cultivating some selected crops in the area. In essence, this study will be carried out to assess the potential for surface irrigation development in the Upper Ogun River Basin.

Aim and Objectives of the Research

The aim of this study was to use geospatial techniques to assess potential of Upper Ogun river catchment for surface irrigation development with a view to generate required baseline information for integrated water resource utilization and irrigated agricultural development.

The specific objectives of the study were to:

i. estimate surface water potential of delineated river catchments.
ii. evaluate the pattern of land cover/use within the catchments.
iii. perform multi-criteria analysis for ranking irrigation suitability of identified agricultural lands.

Justification of the Research

The importance of assessing surface water towards Planning and sustainable management of water resources for irrigation in many parts of the world has been highlighted by many researchers. Its benefits to agriculture include enhancement of productivity of the agricultural land and improvement in its yield (Takeshima & Adeshugba, 2015), increased participation by the private sector in agriculture and creation of viable employment for the country's teeming youths (Arigor *et al.*, 2015; Ogundele, 2007), stronghold for future economic sustainability of the country (Omorogbe *et al.*, 2014), sustenance of the production of growing food demand (Cosmas *et al*., 2010; Olayide *et al*., 2016).

A review of previous studies on the subject shows not much have been done in Nigeria to identify suitable areas for irrigable agriculture as most of the available irrigation facilities are restricted to some kinds of cropping system and regions. Furthermore, people in the study area though having access to a huge volume of impounded water still generally practice rain fed agriculture. The few that get involved in commercial mechanized farming are used to traditional irrigation method of water pumping in the downstream of the dam throughout the river basin. Additionally, there has not been a holistic attempt in the study area towards suitable site selection for irrigation assessment. That is the main reason to conduct this research to identify potential areas for surface irrigation in the Upper Ogun River Basin.

Description of the Study Area

Nigeria is a coastal country, with a land area excluding coastal waters of approximately 923,770 km^2, situated in West Africa. It is approximately located geographically between the latitudes 4° 16' and 13° 52' north of the Equator, and longitudes 2° 49' and 14° 37' east of the Greenwich Meridian. Nigeria is bordered to the north by Niger, to the east by Chad and Cameroon, to the south by the Gulf of Guinea of the Atlantic Ocean, and to the west by Benin. Ogun-Osun River Basin is located in the South Western region of Nigeria within the western littoral hydrological zone. It is geographically located within latitude 6° 30' and 8° 20' N and longitude 3° 25' and 5° 10' E with a land area of 101,802 km^2, which is about 11% of the total area of the country. Ogun river basin which is the focal point of this study has an approximate surface area of 2,237,000 hectares and has the second largest surface area only behind the Cross river (Ita and Sado *et al,* 1985). Both the Ogun and Osun rivers are fed by rivers originating from the Yoruba highlands. They flow slowly from north to south into the Lagos lagoons before discharging through creeks and swamps into the Atlantic Ocean. The topography of the study area consists of mountains and hills in the north end where the source of the rivers is located but as the rivers flow southward, they hit plains underlain by soft, geologically young sedimentary rocks and gently undulating plains, which gets waterlogged during the rainy season. Due to the erosion and sediment transport, the soils in the basin have developed into alluvial parent materials. The basement complex in the upper part of the basin gives rise to a wide variety of soils, coarse in texture and of low fertility. The soils in the basin are classified into two groups based on location and elevation (OORBA, 1982). These are the upland soils, which are more developed and range from heavy and hydromorphic to coarse and well-drained and the lowland soils, which are hydromorphic and affected by a high ground water table and seasonal flooding. Water resources in Ogun-Osun River Basin include surface water and groundwater. Surface water plays a prominent role in the basin. Due to the relative abundance of surface water in the basin, groundwater holds less significance for crop cultivation and consumption (Raphael et al, 2016).

The climate is influenced by the movement of the Inter-Tropical Convergence Zone (ITCZ), a quasi-stationary boundary zone, which separates the sub-tropical continental air mass over the Sahara and the equatorial maritime air mass over the Atlantic Ocean (Adeboye, 2015). The maximum and minimum relative humidity value is found in the rainy months (July, 89.5%) and dry months (March, 74.2%), respectively. In the wet season, the mean rainfall ranges between 1,020 and 1,520 mm in the south of the basin, but in the north, it is less than 1,020 mm. In the North and South, the mean dry season rainfall varies from 127 to 178 mm and 178 to 254 mm, respectively (Raphael *et al*, 2016). The record of temperature in the basin shows that the hottest months are February and March during which temperatures are high. For the month of February, the mean daily maximum temperature is 32°C in the North. The minimum temperature during harmattan in the North is 47°C. During the rainy season in July, a lowest mean minimum temperature of about 22.8°C was recorded (OORBA, 1982).

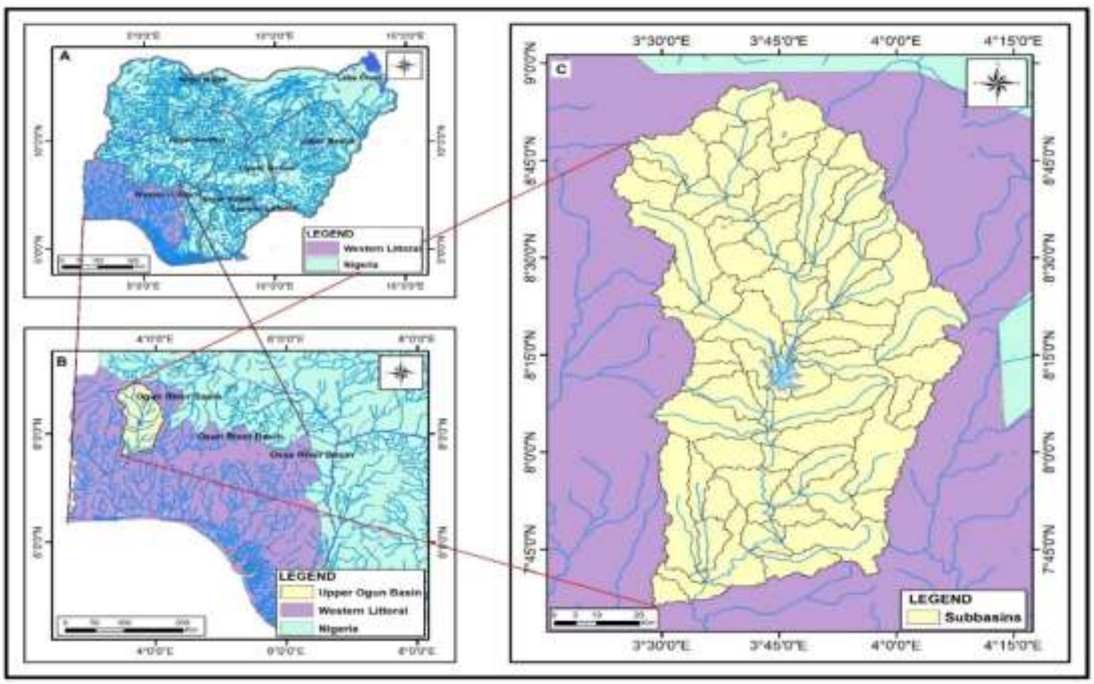

Figure 1. Geographic Location of the Study Area (Source: Authors)

Table 2. Mean Monthly rainfall for 2020 (Source: WorldClim Database)

Month	Mean Rainfall (mm)	Mean Temperature (^{0} C)
January	0.42	21
February	0.9	21.4
March	160.05	13.48
April	239.16	14.26
May	132.64	12.52
June	282.03	10.24
July	105.22	9.38

August	37.79	13.49
September	228.85	9.98
October	196.11	13.97
November	4.1	16
December	3.95	18.71

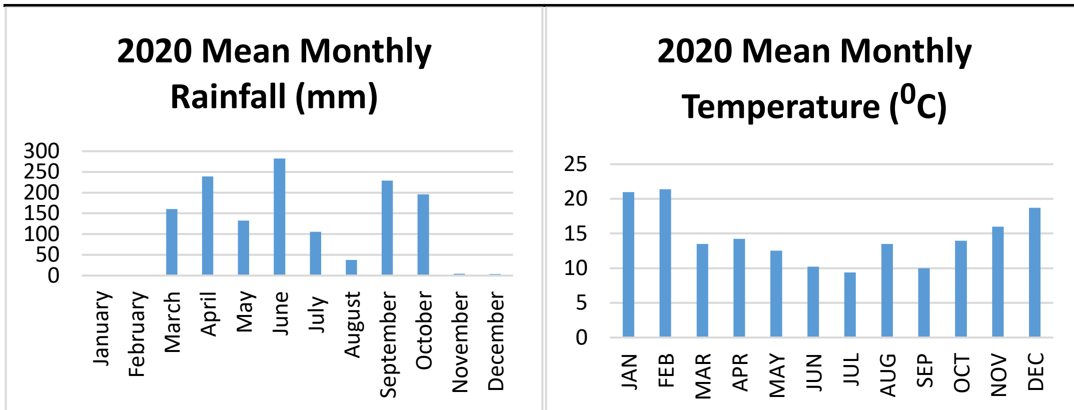

Figure 2. Mean Monthly Rainfall and Temperature Chart of the Study Area (Source: Authors)

The main vegetation patterns run in broad east-west belts, parallel to the Equator. Mangrove and freshwater swamps occupies the basin's outlets to the Atlantic Ocean. Going inland, the swamps give way to dense tropical rainforests. Economically valuable, the oil palm grows wild and is usually preserved when forest is cleared for cultivation. Tropical grassland (in other words Savanna) occupies the area north of the basin where the rivers have their sources. The agriculture production system in the area is a subsistence type of crop and livestock production system. Due to high population pressure, the land is moderately to intensively cultivate. Generally, the Ogun River Basin is renowned for rain fed crops production. Major types of crops grown in the area includes maize, cassava, millet and small extent pulses and oil crops. In this River Basin, some farmers practice traditional irrigation development activities from perennial rivers and springs.

Scope of the Research

This study is limited to Upper Ogun River catchment in Oyo state, Nigeria. The Land Use Land Cover classification is limited to vegetated and non-vegetated areas and hydrological analysis is limited to potential surface water only. This study mainly focuses on identifying potentially irrigable lands suitable for agricultural development within the Upper Ogun river catchment. The factors considered in this study include rainfall, slope, soil, land cover/use, proximity to river, road, existing farm settlements and markets.

METHOD AND MATERIALS

Research Design

This study focuses on employment of Remote Sensing processes and products as well as the application Geographic Information System (GIS) techniques to assess and map water and land resources potential for integrated development of surface irrigation system in the Upper Ogun river catchment. Both qualitative and quantitative parameters of spatial and attribute data were analyzed.

Materials (Data Acquisition) and System Requirements

The employment of appropriate datasets and collection methods are very sacrosanct to achieving the research objective. This Research utilized materials (data) from both primary and secondary sources. The data collection methods included field observation and measurements, download of SRTM and Landsat images from United States Geodetic Survey (USGS) website as well as Sentinel-2 image from European Space Agency (ESA) website, requesting and downloading other relevant data such as reports, shape files, gridded raster files, maps, etc. from responsible organizations and websites and lastly but not the least, interviews with farmers and residents. The main materials from reliable sources adopted for the research work as well as their mode of utilization and established constraints to their adoption to ensure they meet specified accuracy limits for their intended applications are henceforth discussed.

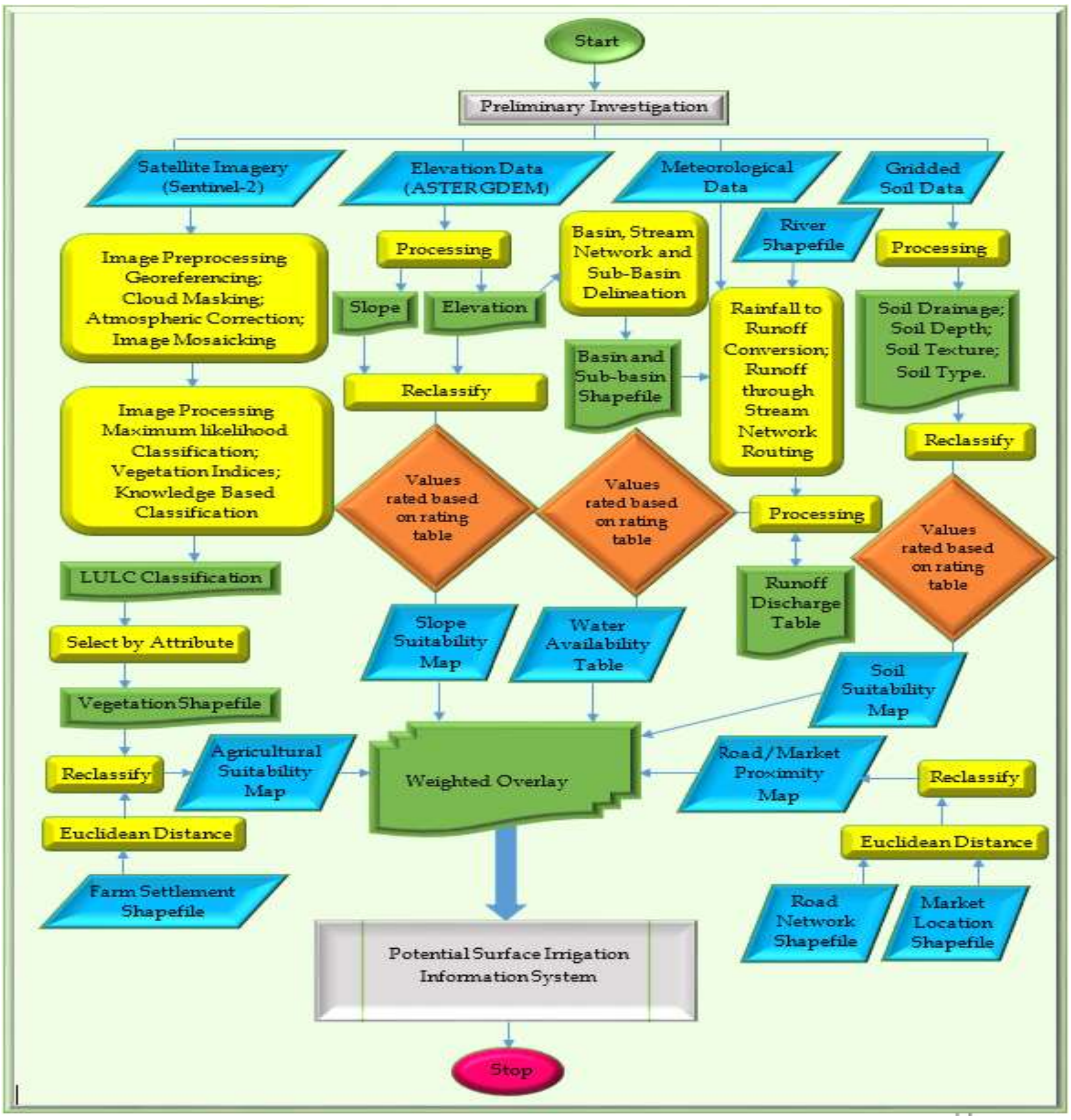

Figure 3. Schematic Workflow of the Research (Source: Authors)

Table 3. Materials (Data), Sources and Use (Source: Authors)

S/N	Material	Source	Purpose
1	Point data and Terrestrial image	Garmin GNSS Receiver & Mobile Camera	for Ground truth verification and accuracy assessment of remotely sensed images and other data sources
2	Satellite imagery	European Space Agency (ESA)	for classification of land cover of the study area
3	Shape files and Raster files	DivaGIS & ArcGIS Online	for extraction of the study area and other input data into the GIS analysis
4	Hydrological data	Nigeria Hydrological Services Agency	for assessment of water resources potential of both gauged and un-gauged sites for irrigation purpose
5	Meteorological data	NiMet & WorldClim	for the estimation of streamflow at un-gauged sites from gauged sites
6	Soil data	ISRIC	for soil suitability analysis for irrigation
7	Elevation data	United States Geological Survey (ASTER GDEM)	to delineate watersheds and to derive slope maps of the study area for irrigation suitability analysis

Data Quality

Data Pre-Processing and Checking

Collected data usually contain errors due to failures of measuring device or the recorder. So, before using such data for any specific purpose, they have to be checked and errors have to be removed**.** Measures taken included ensuring consistency of stream flow and rainfall data, filling missing rainfall data and ground truth check on supervised image classification, downloaded road, river and other feature shape files.

1. Consistency of Stream Flow and Rainfall Data

To prepare the stream flow and rainfall data for further application, their consistency was checked using double mass curve analysis. A plot of accumulated discharge/rainfall data at site of interest against the accumulated average at the surrounding stations is generally used to check consistency of stream flow /rainfall data. To check the degree of consistency, Nemec (1973) provided the value of coefficient of correlation as follows:

$r = 1$: direct linear correlation

o.6 $\leq r < 1$: good direct correlation

$-0.6 < r < 0$: insufficient – reciprocal correlation

$-1 < r < 0.6$: good reciprocal correlation

$r = -1$: reciprocal linear correlation

The stream flow and rainfall data are relatively consistent if the periodic data are proportional to an appropriate simultaneous period, and of these data, which are inconsistent, can be adjusted by proportioning, using correlation coefficient, between stations (Selesh, 2000, Moutaz, 2001 and Yarahmad, 2003).

2. Filling Missing Rainfall Data

Missing records of the rainfall stations were estimated by using normal ratio method which is recommended to estimate missing data in regions where annual rainfall among stations differ by more than 10% (Dingman, 2002). This approach enables an estimation of missing rainfall data by weighting the observation at N gauges by their respective annual average rainfall values as expressed by equation 3.1 (Yemane, 2004).

$$Px = \frac{1}{n}\left(\sum \frac{Px}{Py} * Pg\right) \qquad (eqn.\ 4)$$

The monthly maximum and minimum temperature values at meteorological stations have been averaged into maximum and minimum long term monthly values. These values were used as input data for evapotranspiration computations. Other climatic data such as sunshine duration, relative humidity and wind speed data have been also averaged into long term mean monthly values and used for evapotranspiration calculation.

Data Processing

Watershed Delineation

The hydrological zones and river basins boundaries raster file was vectorized through digital data conversion with the aid of ArcGIS 10.8. The vector file was exported and saved as a shapefile in ESRI file format. The drainage boundaries were extracted from the ASTER GDEM raster image file through masking with the vectorized file. The delineation process requires a Digital Elevation Model (DEM) in ESRI grid format. The DEM file was imported to HEC-HMS 4.7.1 and projected to UTM Coordinate system then used to create a basin model for the hydrologic process. The methods to be adopted for the hydrologic processes were set at the initial stage for simplicity. Terrain data was preprocessed to identify and locate sinks (fills) within the region of interest. Flow directions for individual DEM cells were created using flow direction and accumulation tool. HEC-HMS computes flow direction and accumulation grid for individual DEM cells and uses defined stream threshold area in hectares to create streams and their respective accumulation rate based on these directions and automatically segment the stream network.

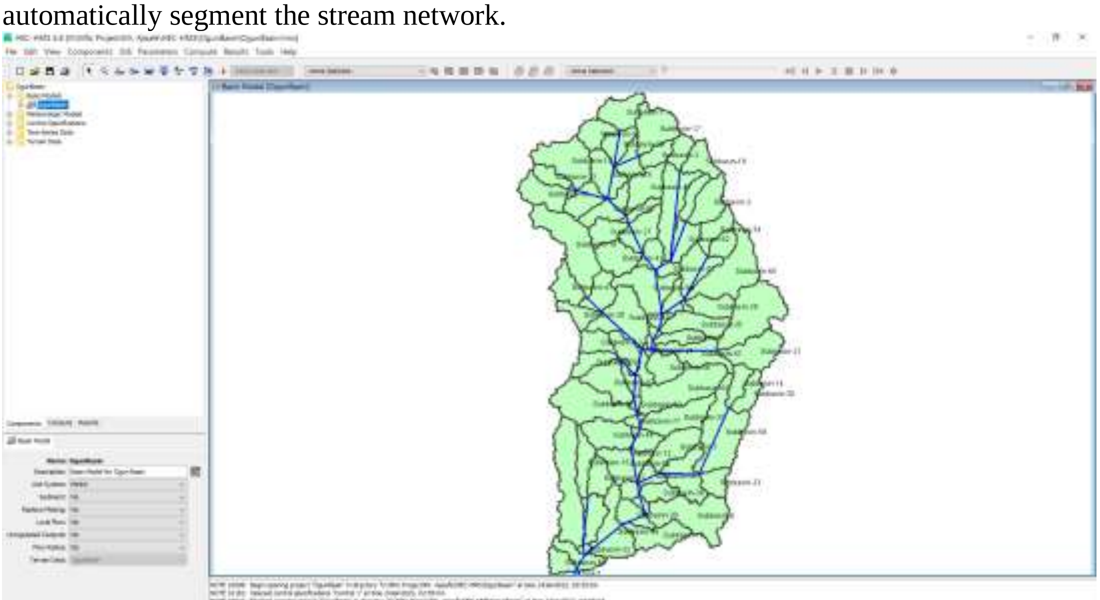

Figure 4. Watershed Outlets and Boundaries

An outlet, or pour point, is the point at which water flows out of an area. This is the lowest point along the boundary of the watershed. The cells in the source raster are used as pour points above which the contributing area is determined. By using break point creation tool in

HEC-HMS, the watershed outlets are defined as shown in Figure 4. The main watershed was automatically delineated by using delineate element tool in HEC-HMS using the watershed outlets created. In order to create sub-watersheds, additional drainage outlets need to be defined. After several nodes or vertices are defined into drainage outlets along the stream arcs, the same method defining watershed outlets in step 3 was used again to delineate sub-watershed.

Identification of Potential Irrigable Sites

Identification of suitable sites for irrigation was carried out giving consideration to relief, soil, land cover/use and distance between water supply and the potential command area as main factors. The individual suitability of each factors was analyzed first and then weighted to get potential irrigable sites. The process involves slope suitability analysis, soil suitability assessment, Land cover/use classification, proximity to water source and farm settlement, road and market accessibility and weighing of irrigation suitability factors to find potential irrigable sites.

1. Slope Suitability Analysis

To derive slope suitability map, the DEM was clipped from 12.5-meter resolution ASTER GDEM by masking the layer of the study area boundary. Then slope maps of the area and watersheds were derived using the "Spatial Analysis Slope" tool in ArcGIS 10.8. The Slope derived from the DEM was classified based on the classification system of FAO (1996). The four (4) suitability ranges (S1, S2, S3 and N) are shown in Table 4.

Table 4. Slope suitability classification for surface irrigation (Source: FAO, 1996)

Legend	Slope (%)	Factor rating
1	0-2	S1
2	2-5	S2
3	5-8	S3
4	>8	N

The classified raster data layers were then converted to feature (vector) data layers for the overlaying analysis. Using data management tools in Arc Tool box, generalization of the feature (vector) data layers was performed to make a clearer slope suitability map.

2. Soil Suitability Assessment

For soil suitability assessment, the major soil groups in the study area were classified and the physical properties of these soil groups was used for irrigation suitability analysis. To assess soil suitability for irrigation, the Harmonized World Soil Database was used. It is available in ARC/ INFO format with scale of 1:1000000. The major soil groups classified in the study area were: Acrisols, Alisols and Arenosols. Physical properties of these soil groups were used for irrigation suitability analysis. The following soil suitability rating was used based on the FAO guidelines for land evaluation (FAO, 1976, 1979, 1990, 1991) and FAO (1997) land and water bulletin.

Further, the soil vector layer was converted into raster layer using conversion tool "To Raster or Feature to Raster module". The rasterized soil map of the study area was then reclassified based on their soil type, texture, depth and drainage classes. Using overlay tool in Arc GIS 10.8 Spatial analyst, weighted overlay analysis of these factors were performed to determine their suitability for surface irrigation. Then, the new values were reassigned for each soil factor in order of their irrigation suitability rating based on common evaluation scale from 1-9 available in weighted overlay analysis. A value 1 represents the least suitable factor in evaluation while, value 9 repents highest suitable factor in evaluation. Soil factor that is highly suitable was given a value 9, for moderately suitable factor was given a value 6, for marginal suitable factor was given a value 3 and for least suitable factor was given a value 1. When scale values from 1-9 is not assigned for soil factors in evaluation, that cell value is restricted for surface irrigation and it should be excluded from evaluation. For example, a soil factor with soil depth 10cm is restricted for surface irrigation development and the cell value representing this value is assigned as 'restricted scale' so that it will be excluded from the evaluation.

Table 5. Soil suitability factor rating (Source: FAO guideline for land evaluation, 1976, 1979 & 1991)

Factors	**Factor rating**			
	S1	S2	S3	N
Drainage class	Well	Imperfect	Poor	Very poor
Soil depth (cm)	>100	100-80	80-50	<50
Soil texture	L-SiCL, C	SL	-	-
Soil type	Alisols	Arenosols	Acrisols	-

3. Land Cover/Use Characterization

Land cover/use of the study area is also another important factor used to evaluate the land suitability for irrigation. In this research, the classification was done using Sentinel-2 satellite image for identification of land cover classes to estimate potential irrigable land. ENVI 5.3 software was used in conjunction with ArcGIS 10.8 and Google Earth for image pre-processing, classification, accuracy assessment and compilation of final land cover/use map. Successful identification of land cover usually requires multi-temporal images. The choice bands among the downloaded Sentinel-2 satellite image files were imported into ENVI5.3 directly. Then true color composite images were created by combining the spectral bands that most closely resemble the range of vision of the human eye which in the Sentinel-2 images are normally used for land cover analysis. A true-color composite uses the visible red (band 4), visible green (band 3), and visible blue (band 2) channels to create an image that is very close to what a person would expect to see in a photograph of the same scene as shown in Figure 5. The other image pre-processing steps, such as image rectification and restoration and image enhancement, were also performed.

Prior to the field work, unsupervised classification from the Sentinel-2 image was conducted to understand the general land cover classes of the study area. Based on results from unsupervised classification and information from topographic map of the study area, sample training sites were selected to collect geographic coordinates and field photographs during the field work. The geographic coordinate values of field photographs were then added to the Sentinel-2 image by Ground Control Points Selection dialog box in ENVI 5.3. This process, therefore, establishes the framework of the GCPs positions of the pixels for output image. The problem then is to decide how best to examine the different land cover signatures at pixels in the image and comparing field photographs of the same GCPs locations with the unclassified image. This information was then used in the selection region of interest for the supervised classification. By using supervised classification with Maximum Likelihood method, seven land cover classes were classified for the study area except towns, which were not separable and they were classified by masking using their polygon layers.

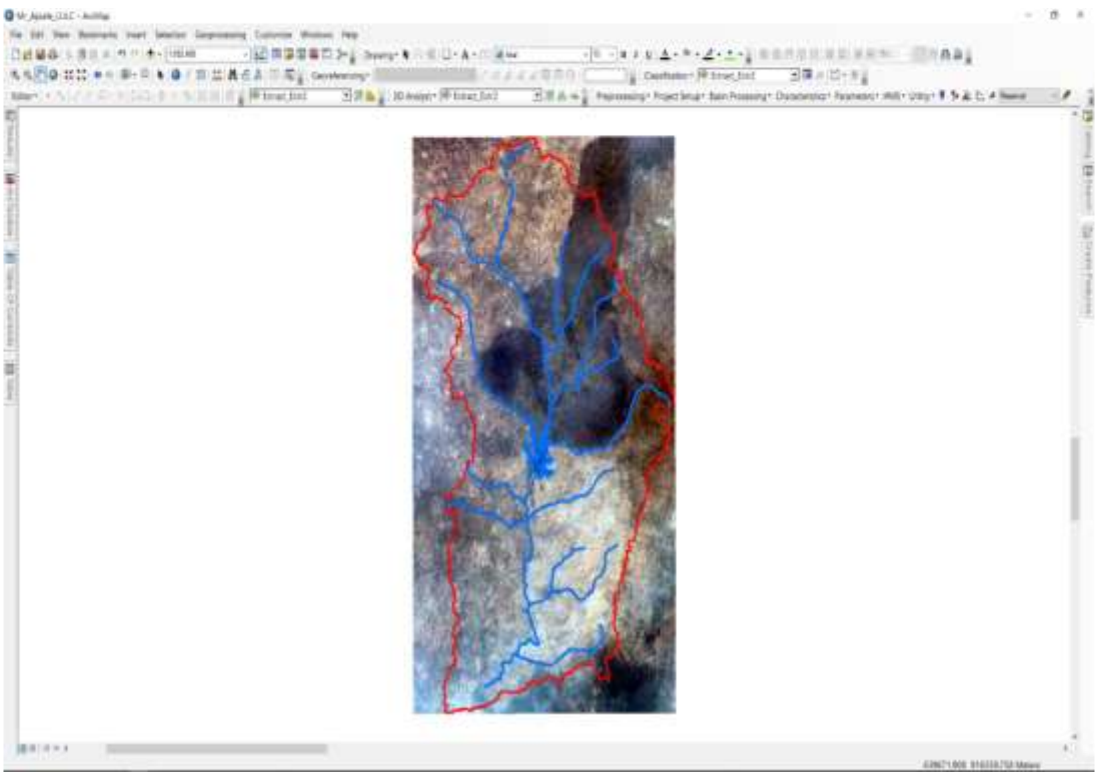

Figure 5. Sentinel-2 Satellite Image of the Study Area Showing True Color Composite (432)

Accuracy Assessment: To validate and crosscheck the result of the image classification with known ground truth data, accuracy assessment was checked for the signature values of the classified images by calculating the confusion matrix in ENVI 5.3 software. The confusion matrix is a table with the columns representing the reference (observed) classes and the row the classified (mapped) classes (Rossiter, 2001). The ground truth data were used in the maximum likelihood report as the independent dataset from which the classification accuracy was compared. The accuracy is essentially a measure of how many pixels in the ground truth

Region of Interests (RoIs) were classified correctly. The overall accuracy was calculated by summing the number of pixels classified correctly and dividing by the total number of pixels. Kappa coefficient represents strong agreement between classified land cover classes and observed land cover/use (Ephrem, 2007). It lies between 0 and 1, where 0 represents weak agreement and 1 represents strong agreement. According to Rahman *et al* (2006), kappa values can be classified into three: the value greater than 0.8 represents strong agreement, between 0.4 and 0.8 represents moderate agreement and a value below 0.4 represents poor agreement. Equation 3.2 gives mathematical relationship for calculating kappa coefficient in ENVI5.3 software.

$$Kappa(K) = \frac{Po - Pe}{1 - Pe}$$

(eqn. 5)

Where,

Po = is the proportion of correctly classified classes

Pe= is the proportion of correctly classified classes expected by chance

Compilation of Final Land Cover/Land Use Map: Classified images require post-processing to generalize classes for export to image-maps and vector GIS. In ENVI5.3 post classification tool, majority analysis was applied to generalize image classification. Then classification to vector tool was used to convert classification results to ENVI polygon vector layers (.evf files) and then exported to shape files, ArcGIS 10.8 - compatible file set. The classified images will have a vector layer for each selected class. Due to the spatial resolution of Sentinel-2 image, a countless smaller polygons were created in the classified image. To produce land cover map of 1:250,000 scale (a common rule of thumb for thematic mapping), it was therefore necessary to filter these polygons so that no polygons were smaller than 50 ha. This processing was performed within Arc Map software using 'Select by attribute tool' and 'Generalization tool' in the Arc tool box. The aim of this process is to generalize the classification by removing small polygons. In this case, polygons were removed if they are less than 50 Ha. The final clearer map with a scale of 1:250,000 was produced

4. Proximity to Water Supply Source

To identify irrigable land close to the water supply (rivers), straight-line (Euclidean) distance from watershed outlets was calculated using DEM of 90mx90m cell size and reclassified. The reclassified distance was used for weighted overlay analysis together with other factors.

5. Weighing of Irrigation Suitability Factors to Find Potentially Irrigable Sites

To find suitable site for surface irrigation, model builder in Arc toolbox and tools from spatial analysis tool sets were used to create a suitability model. Then, after their individual suitability was assessed, the irrigation suitability factors which were considered in this study, such as slope factor, soil factor, land cover /use factor and distance factor were used as the input for irrigation suitability model to find the most suitable land for surface irrigation as shown in Figure 6.

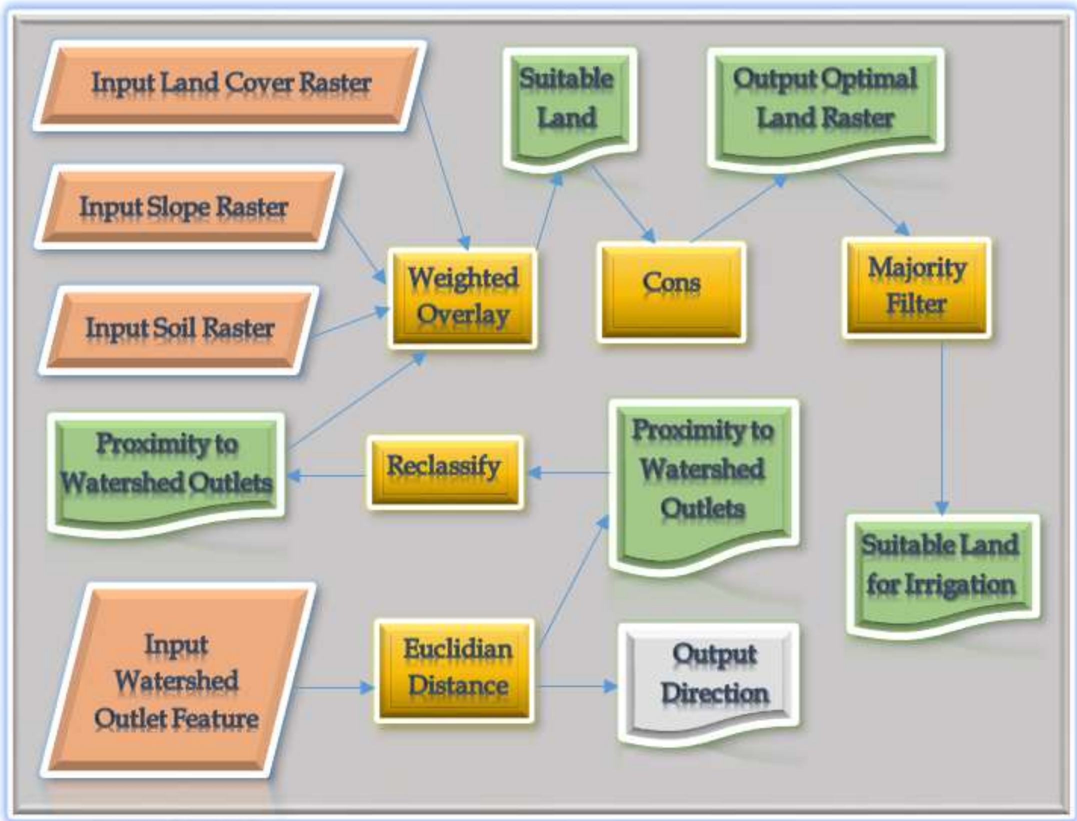

Figure 6. Irrigation Suitability Model (Source: Field Book)

Estimating Surface Water Potential of River Catchments

The available surface water of all the catchments was estimated using stream flow discharges computed from meteorological data of the study area. Using the watershed explorer window on HEC-HMS, the delineated sub-watersheds were explored to be sure they met up with established standards for the establishment of a command area. Sub-watersheds that fall short were merged with adjacent ones. Using the already created stream networks (reaches) and delineated main and sub-watersheds (sub-basin), HEC-HMS creates a schematic network which is used in conjunction with the two to calculate the total accumulated flow at the watershed outlet (pour point).

1. Creating Basin Model for the Catchment and Sub-Catchments

The first operation is to assign SCS curve number as well as other parameters required by the simulation method for the calculation of the amount of water loss during the hydrologic process to each of the sub-basin. The HEC-HMS 4.7.1 used does not have this functionality hence ArcGIS was adopted to generate CN values for the delineated sub-basins. Zonal statistics tool of the Geoprocessing module of ArcGIS Pro was used to generate the curve numbers for the sub-basins using the curve number grid raster file for the delineated basins. The result of this geo-statistical exercise is a generated mean curve number value for each sub-basin which was exported for inclusion in the HEC-HMS process.

One important operation in the hydrologic simulation is to transform the rainfall hyetograph to a hydrograph. For this to be accomplished, there is need to compute lag times and other parameters involved in the transportation of the rain water through terrain surface all the way to the river outlet. An empirical method for determining lag times from curve number requires the determination of the time of concentration. Time of concentration is the time taken by a rainfall drop to travel from the farthest point in the watershed to the outlet. The mathematical equation (model) for their determination is as follows:

$$L = 0.6Tc_2$$

(eqn. 6)

$$Tc = \frac{l^{0.8}(S+1)^{0.7}}{1,140Y^{0.5}}$$

(eqn. 7)

Where,

L = Lag time, h

Tc = Time of Concentration, h

L = Flow length, ft

Y = Average Watershed Land Slope, &

S = Maximum Potential Retention, in

$$S = \frac{1000}{CN} - 10$$

(eqn. 8)

Using the longest flow path length and basin slope calculated by the HEC-HMS and contained on the basin characteristics table, an excel spreadsheet was programmed using the mathematical expressions above to derive the required quantities. The derived lag times which is in hours is then converted to its equivalent in minutes since that is the format HEC-HMS uses then the values are imported to the hydrologic process. Another important quantity for the process is the Initial Abstraction (I_A) value (mm) which the HEC-HMS automatically calculate and assign to each sub-basin using the formula:

$$I_A = 0.2 * S$$

(eqn. 9)

Parameters are assigned for all the reaches (stream networks). The essence of this operation is to quantify the amount of water lost or gain as the runoff travel from its drop point through the stream network to the river outlet. The simulation method applied is the Muskingum method which involved two constants 'K' and 'X'. Calculated values of each of the constant were inputted for each reach (stream).

2. Creating Meteorological Model

The purpose of this process is to create rainfall hyetograph which will be transformed to the required hydrograph utilized for the hydrologic simulation process. The first operation is to create rain gauges for rainfall events within the periods of interest. The downloaded spreadsheet containing the rainfall information is utilized for this operation. On completion, a rainfall hyetograph is generated for each of the sub-basin. A meteorological model created for the basin is linked to the already created gauges.

3. Creating Control Specifications for Hydrologic Simulation

The purpose of this process is to create establish constraints and rules to guide the rainfall event simulation. It also affords the generation of data for periods of missing rainfall data. At this stage, the created basin model and meteorological model are utilized for the setting of controls and the eventual simulation. Once all controls are already set, the hydrologic simulation was initiated and on completion, the results of the hydrologic process were saved.

Ranking of Potential Irrigable Sites Among River Catchments

The identified irrigable lands, estimated water resources (the mean monthly runoff and the mean monthly flows transferred to site of interest from water sources calculated with HEC-HMS) and monthly irrigation water requirements for specified crops should be compared to estimate irrigation potential of the river catchments for the customary cropping system. After identifying irrigation potential of each river catchments, the sites were ranked according to their irrigation potential for irrigation development possibilities. The catchment with the highest irrigation potential were ranked first and so on.

RESULTS AND DISCUSSIONS

Basin (Watershed) Delineation

The basin (watershed) delineation showed that the main channel of the Ogun River has majorly one main basin with all the networks of rivers gravitating towards a single pour point (outlet). Within the main basin, it was discovered there are eighty-four (84) sub-basins, each with a central flow path with identified perennial river systems and stream networks all flowing into a central channel, the Ogun River. The central channel of the basin extensively access water through a network of interconnected rivers and streams and it covers a total land area of **7,875.725556** square kilometers. For the sake of simplicity and coherence, the result presentation here was restricted to the main basin as presenting result for each of the 84 sub-basin will unnecessarily make the presentation too cumbersome. Graphical representation of the sub-basins is shown in Figure 15.

Irrigation Suitability Evaluation Factors

Relief (Slope) Suitability Assessment

Slope is considered one of the major evaluation parameters in irrigation suitability analysis. According to FAO, standard guidelines for the evaluation of slope gradient, slopes which are less than 2%, are very suitable for surface irrigation. But slopes, which are greater than 8%, are not generally recommended (FAO, 1999). Based on the four slope classes Highly suitable (S1), Moderately suitable (S2), Marginally suitable (S3) and Unsuitable (N), the suitability of the study area for the development of surface irrigation system was determined and the area coverage of the suitability classes calculated as shown in Table 12. The results in Table 12 revealed that 79.6% of the total area of the *Upper Ogun River Basin* (covering an area of 6,263.4 km^2) falls within the range of highly suitable to marginal suitable land for surface irrigation system development with respect to slope whereas the remaining approximately 20.5% of the area (covering an area of 1,612.6 km^2) is not suitable. Hence, the majority of the study area passed the test for slope suitability thus can be developed for surface irrigation systems.

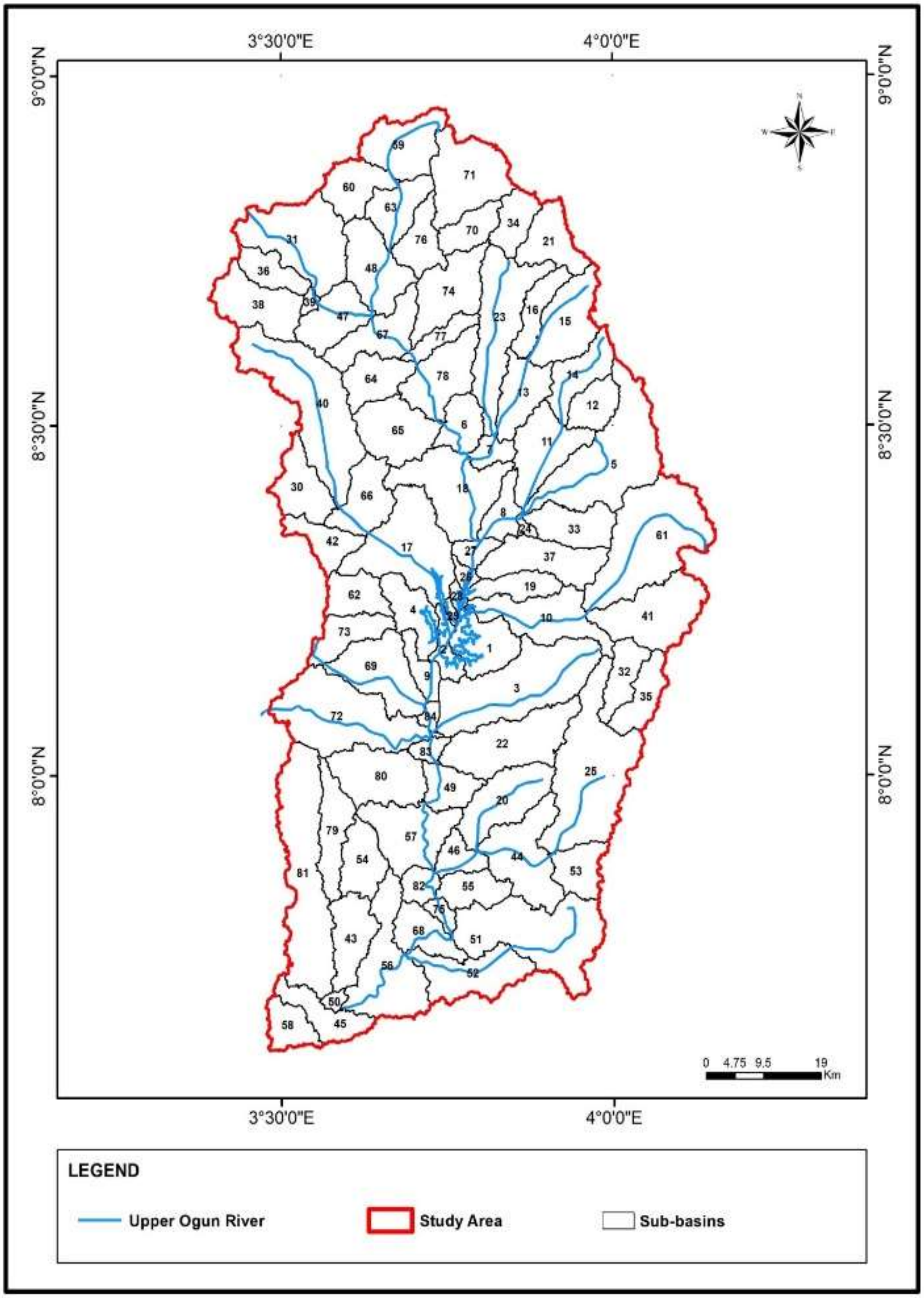

Figure 7. Main and Sub-basins in the Upper Ogun River Basin

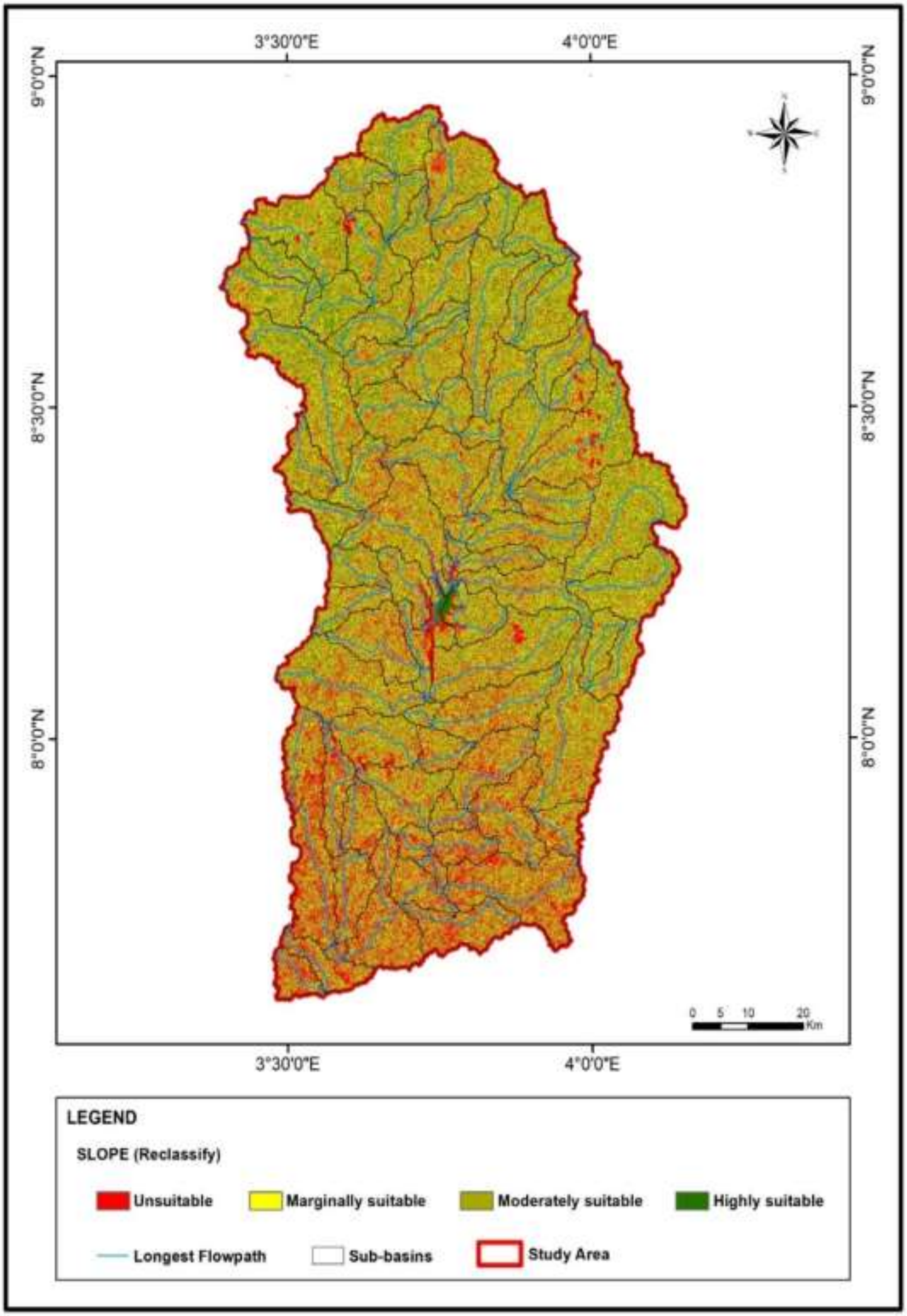

Figure 8. Relief (Slope) Suitability Assessment Map

Table 6. Result of Relief (Slope) Suitability Assessment

Slope Range (%)	Area (Km^2)	Coverage	Percentage of Total Area (%)	Suitability Classes
0-2	847.7		10.8	S1
2-5	3130.8		39.8	S2
5-8	2284.9		29.0	S3
>8	1612.6		20.5	N
Total	**7875.4**		**100.0**	

Soil Suitability Assessment

Soil suitability assessment for this research is limited to the soil's physical properties assessment as relevant to irrigation which include the soil type, depth, texture and drainage and their suitability rating factors were adopted from FAO guidelines. Each element was assessed based on the fitness of their properties for surface irrigation system development against standardized parameters. The general soil types identified in the Upper part of Ogun River Basin include Alisols, Arenosols and Acrisols. Soils considered highly suitable, moderately suitable, marginally suitable and unsuitable have depths of >100cm, 50-100, 25-50 and 0-25 respectively. With respect to drainage, soils considered highly suitable, moderately suitable, marginally suitable and unsuitable are well drained, imperfectly drained, poorly drained and very poorly drained respectively. Soils considered highly suitable and moderately suitable in terms of texture are fine grained and medium grained respectively.

Table 7. Result of Soil Suitability Assessment Area Coverage (km^2)

Suitability Factors	Suitability Classes				Total
	S1	**S2**	**S3**	**N**	
Soil Type	5573.2	841.2	1460.1	-	**7875.4**
Soil Depth	2033.5	3520.5	1310.7	1009.1	**7875.4**
Soil Drainage	2532.2	2598.0	2539.6	205.2	**7875.4**
Soil Texture	6374.6	1500.6	-	-	**7875.4**

Table 8. Result of Soil Suitability Assessment Percentage of Total Area (%)

Suitability Factors	Suitability Classes				Total
	S1	**S2**	**S3**	**N**	
Soil Type	70.8	10.7	18.5	-	**100.0**
Soil Depth	25.8	44.7	16.6	12.8	**100.0**
Soil Drainage	32.2	33.0	32.2	2.6	**100.0**
Soil Texture	80.9	19.1	-	-	**100.0**

Results of these analysis indicate that the study area can be generally classified into three irrigation suitability classes based on soil suitability as a factor: S1 (highly suitable), S2 (moderately suitable) and S3 (marginally suitable). Alisols, covering an area of 5,573.2 km^2

which accounts 70.8% of the total area, was classified as highly suitable (S1) for surface irrigation. This soil is characterized by deep soil, clay texture, well drainage condition and no salinity and alkalinity hazards. Haplic luvisols, Chromic Luvisols and Eutric vertisols were classified as S2 (moderately suitable class). Arenosols are characterized by optimum conditions for surface irrigation system in terms of all factors except that both are limited by sandy loam texture. Similarly, Acrisols are limited by their imperfect drainage condition while the other factors are optimum for surface irrigation. In general, about 10.7% of the land in the study area (841.2 km^2) can be categorized as moderately suitable (S2 class) for surface irrigation. These soils are classified as S2 because of the presence of the factors limiting the land for the specified use (FAO, 1979). However, S2 can be transferred to S1 using the most appropriate irrigation methods such as sprinkler and drip irrigation on these soils. The study established that there is no land in the study area with soil types that can be categorized as N (not suitable) for surface irrigation (see Figure 9-12).

Land Cover/Use Evaluation

From Sentinel-2 satellite image supervised classification, six land cover/use classes were originally identified. These classes include shrub land, cultivated land, dense natural forest, grass land, constructed land and water body. These were further reclassified as indicated Table 9 and Figure 13.

Referring to Figure 13 and Table 9, *Cultivated Land* cover type is dominant as compared to the other land cover types in the study area. It covers 78.4% of the total area of the *Upper Ogun River Basin*. As stated in section 3.1, *Upper Ogun River Basin* consists of 84 sub-basins and the cultivated land cover type is found in all those sub-basins. *Forest land* mainly lies within the old Oyo National Park just at the tip of the Ikere gorge dam covering an area of 19.7% of the total area of the study area. *Built-Up Area* covers urban areas such as Oyo, Iseyin and Ogbomoso towns covering an area of 1.4% of the total area of the study. *Water Body* covers some part of Ikere gorge dam in the study area occupying 0.6% of the study area.

The Framework of land suitability classification (FAO 1976) was adopted as the basis for the supervised classification. Farmlands, intensively cultivated lands and moderately cultivated lands were classed as highly suitable (S1), while sparsely cultivated lands were categorized as moderately suitable. Grassland, shrub-land and seasonal wetland were considered as marginally suitable. Dense natural forest, ponds, dams, and urban areas are considered as not suitable. For the sake of simplifying this research, the identified land cover classes were reclassified basically as vegetated and non-vegetated lands thus the available suitability classes were grossly distributed between highly suitable and not suitable classes as shown in Figure 14 and other details indicated in Table 19. Land cover/use classes such as cultivated and shrub grass land were classified as highly suitable for irrigation with the assumption that these land cover classes can be irrigated without limitations. They cover 78.4% of the study area. Other land units such as grazing and forest lands were classified as lands not suitable for irrigation. This is because according to the local culture land use reserved for these purposes can’t be put under cultivation. It is obvious that land cover classes such as degraded shrub land, settlement/urban areas, water body or lake and wet land cover classes are restricted to use for irrigation. Therefore, the land cover that was not suitable for surface irrigation accounts for 21.6%.

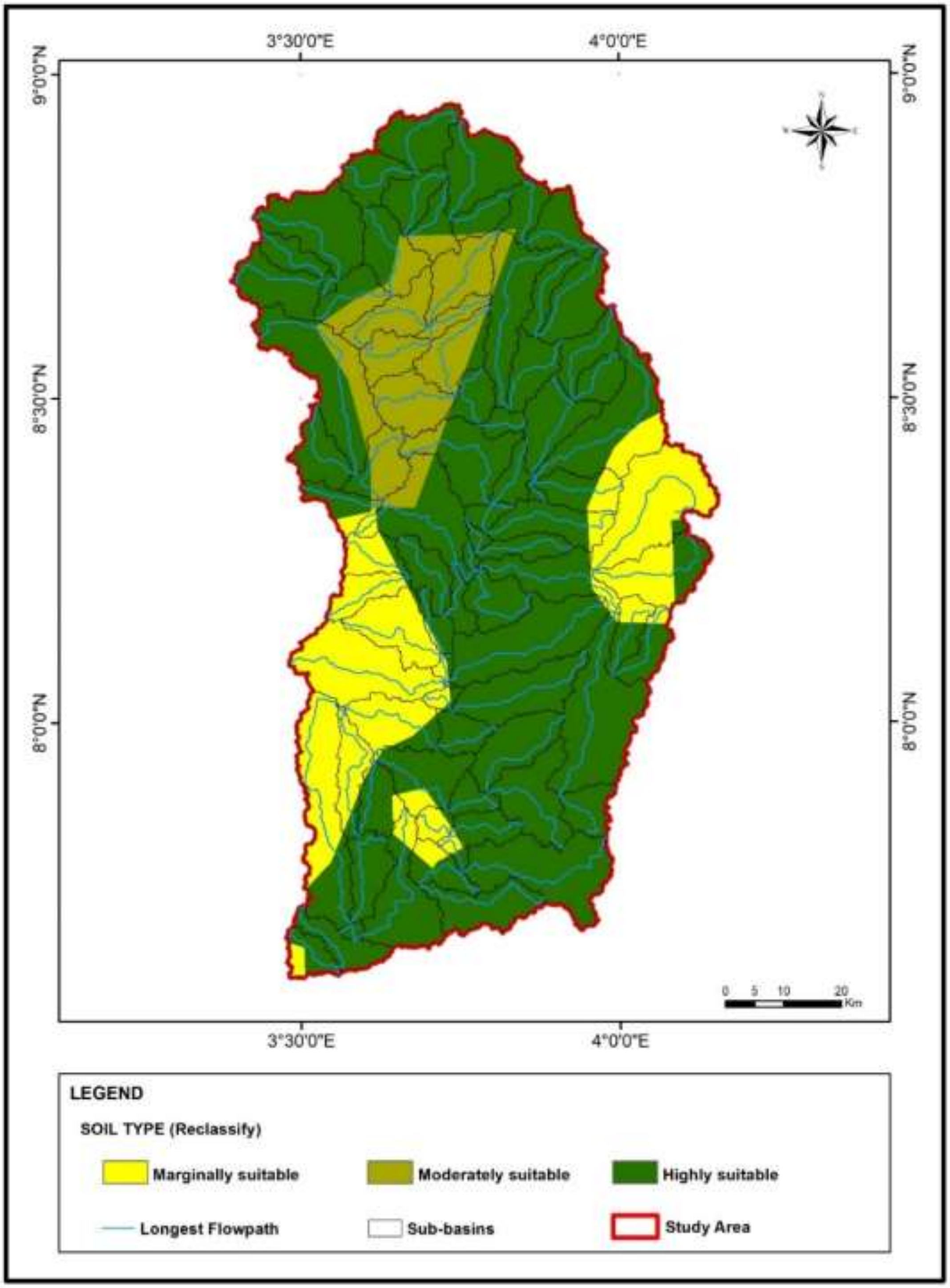

Figure 9. Soil Type Suitability Assessment Map

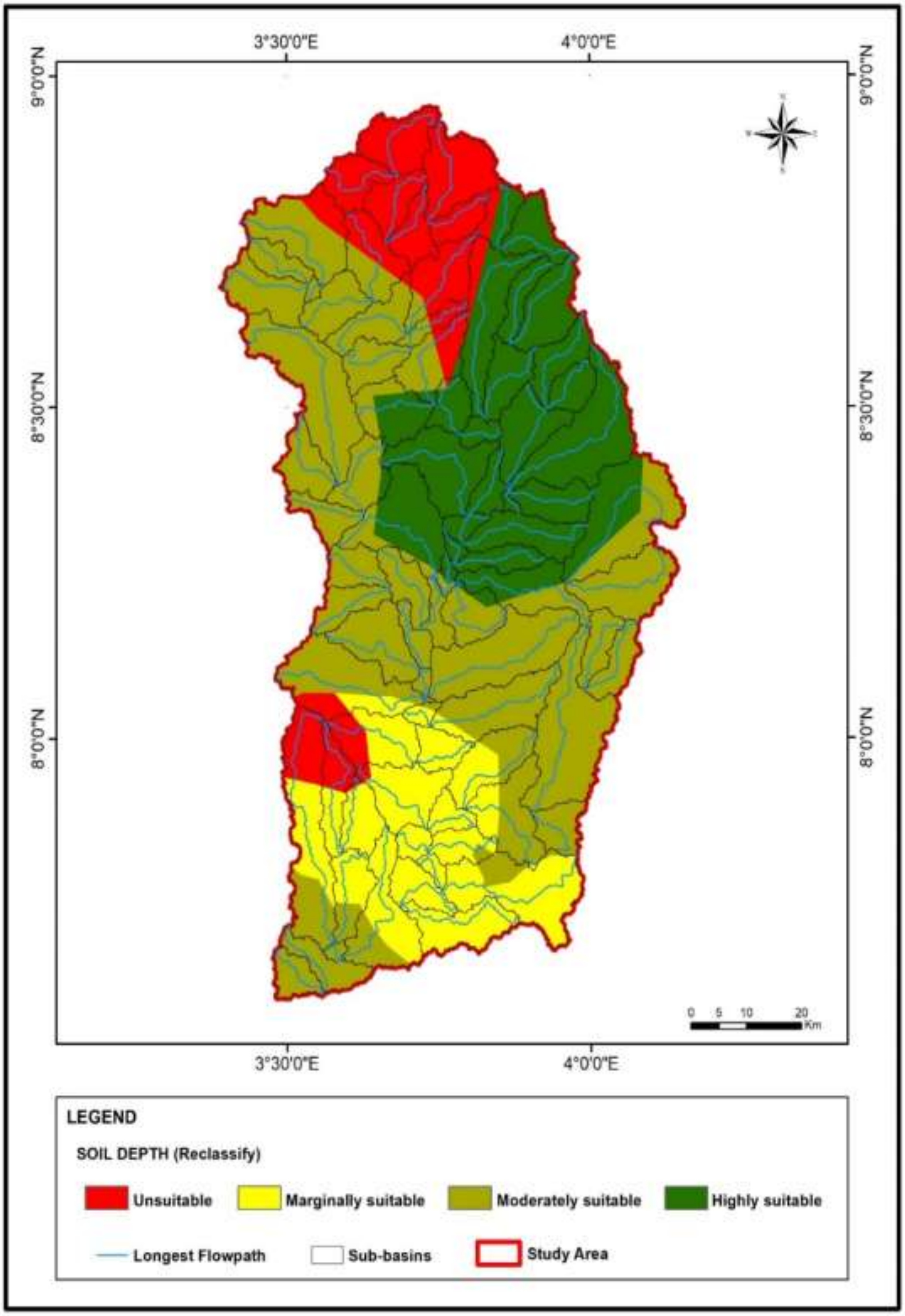

Figure 2. Soil Depth Suitability Assessment Map

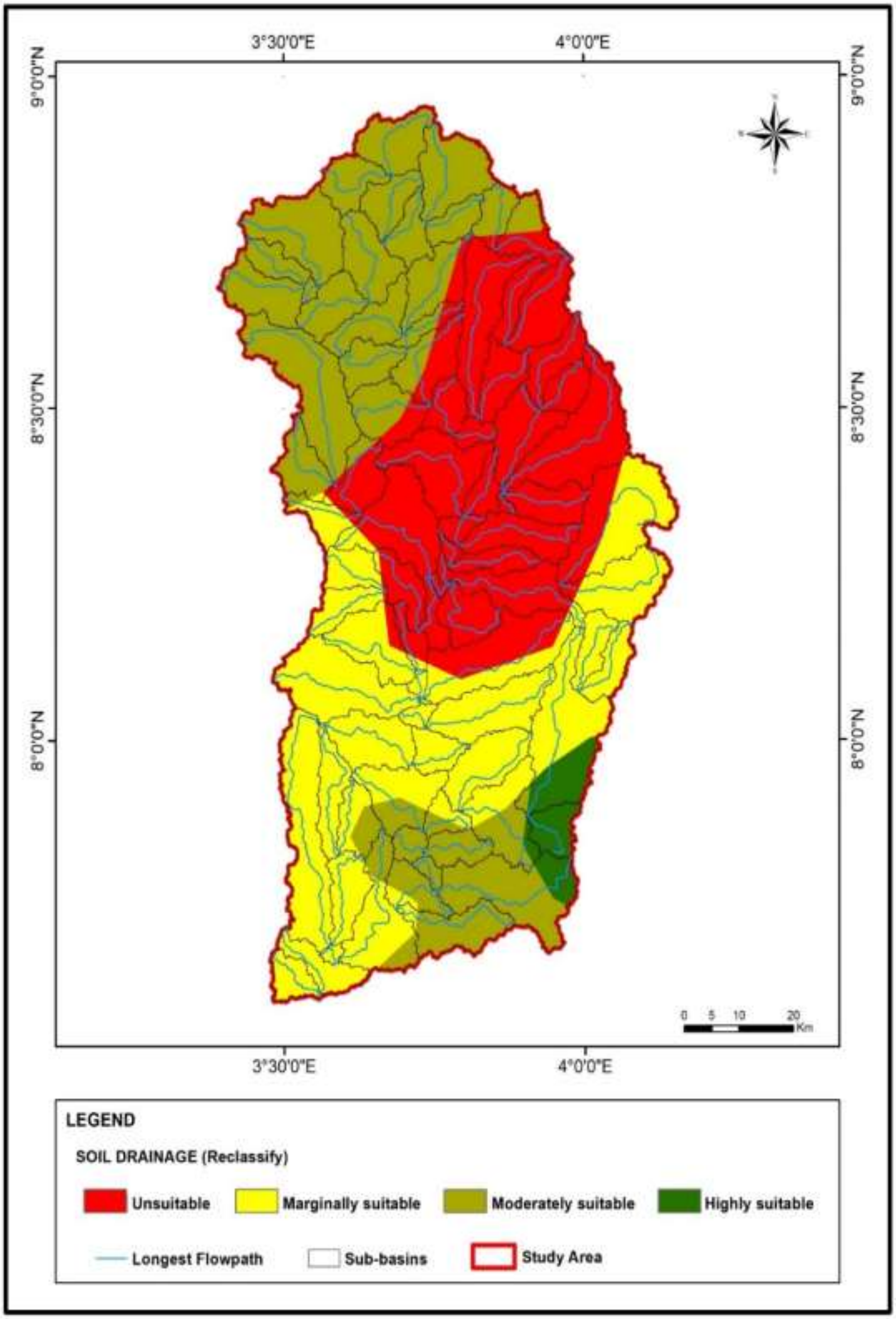

Figure 3. Soil Drainage Suitability Assessment Map

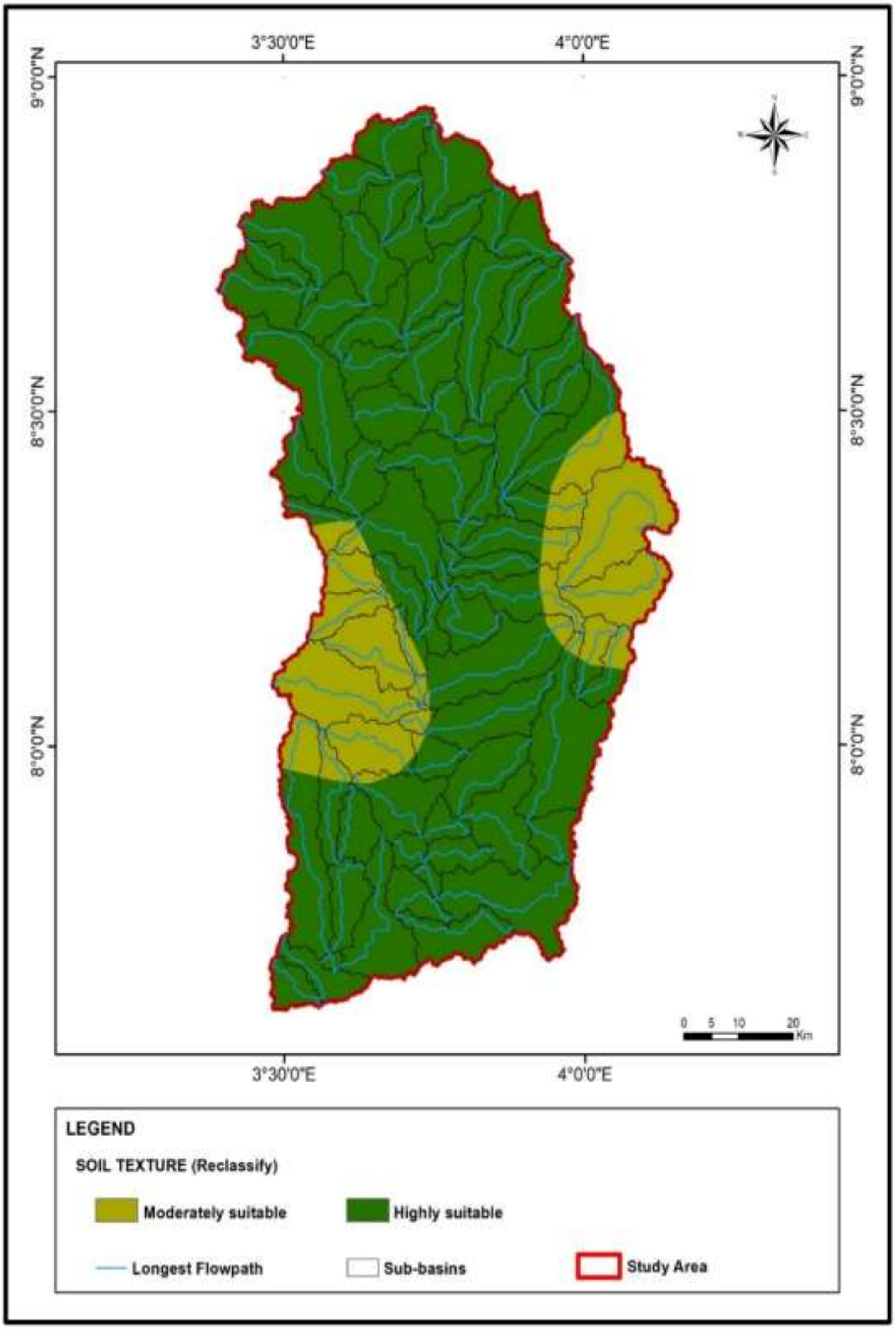

Figure 12. Soil Texture Suitability Assessment Map

Table 9. Result of LULC Classification

Land Cover/Use Class Name	Area Coverage (Km^2)	Percentage of Total Area (%)
Built-up Area	107.6	1.4
Cultivated Area	6173.1	78.4
Forest	1550.9	19.7
Waterbody	43.7	0.6
Total	**7875.4**	**100.0**

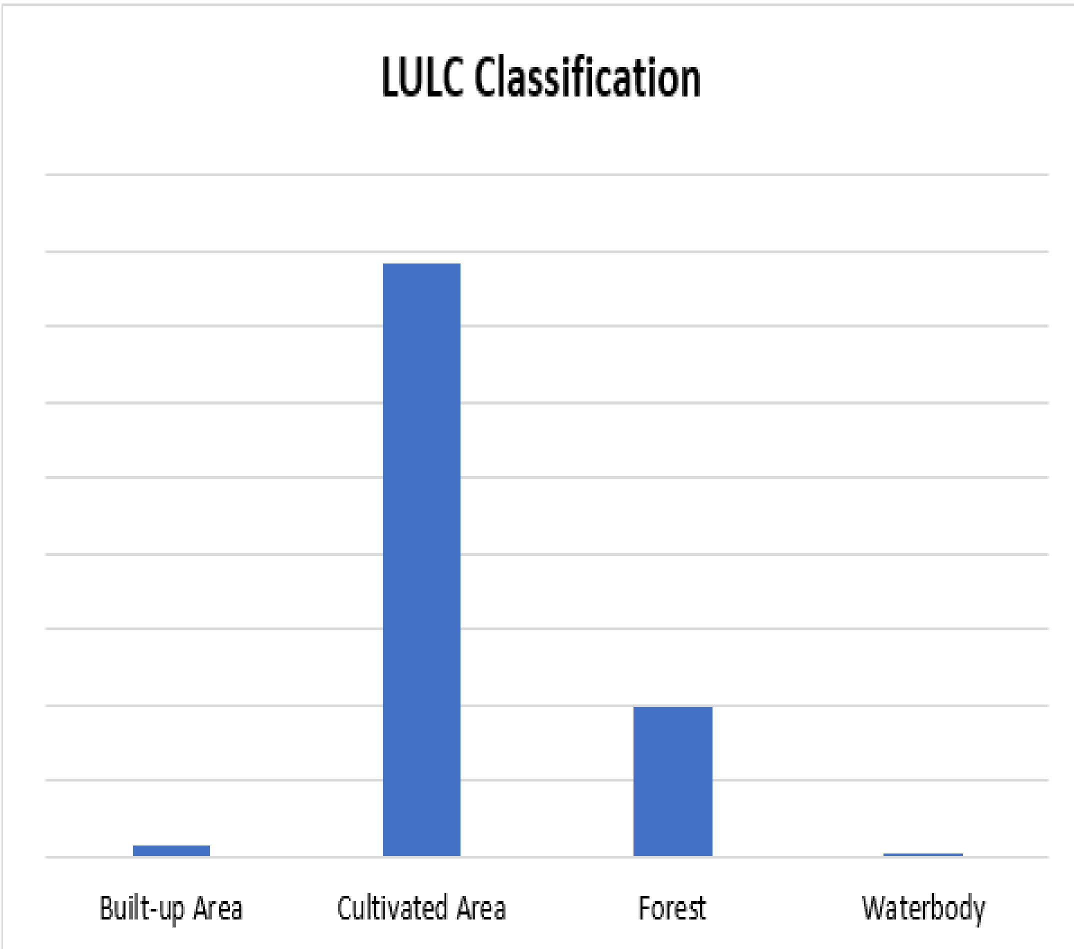

Figure 13. LULC Classification Result Bar Chart

Table 1. Result of Land Cover/Use Suitability Evaluation

Land Cover/Use	**Area Coverage (Km^2)**	**Percentage of Total Area (%)**	**Suitability Classes**
Highly suitable	6173.1	78.4	S1
Non suitable	1702.2	21.6	N
Total	**7875.4**	**100.0**	

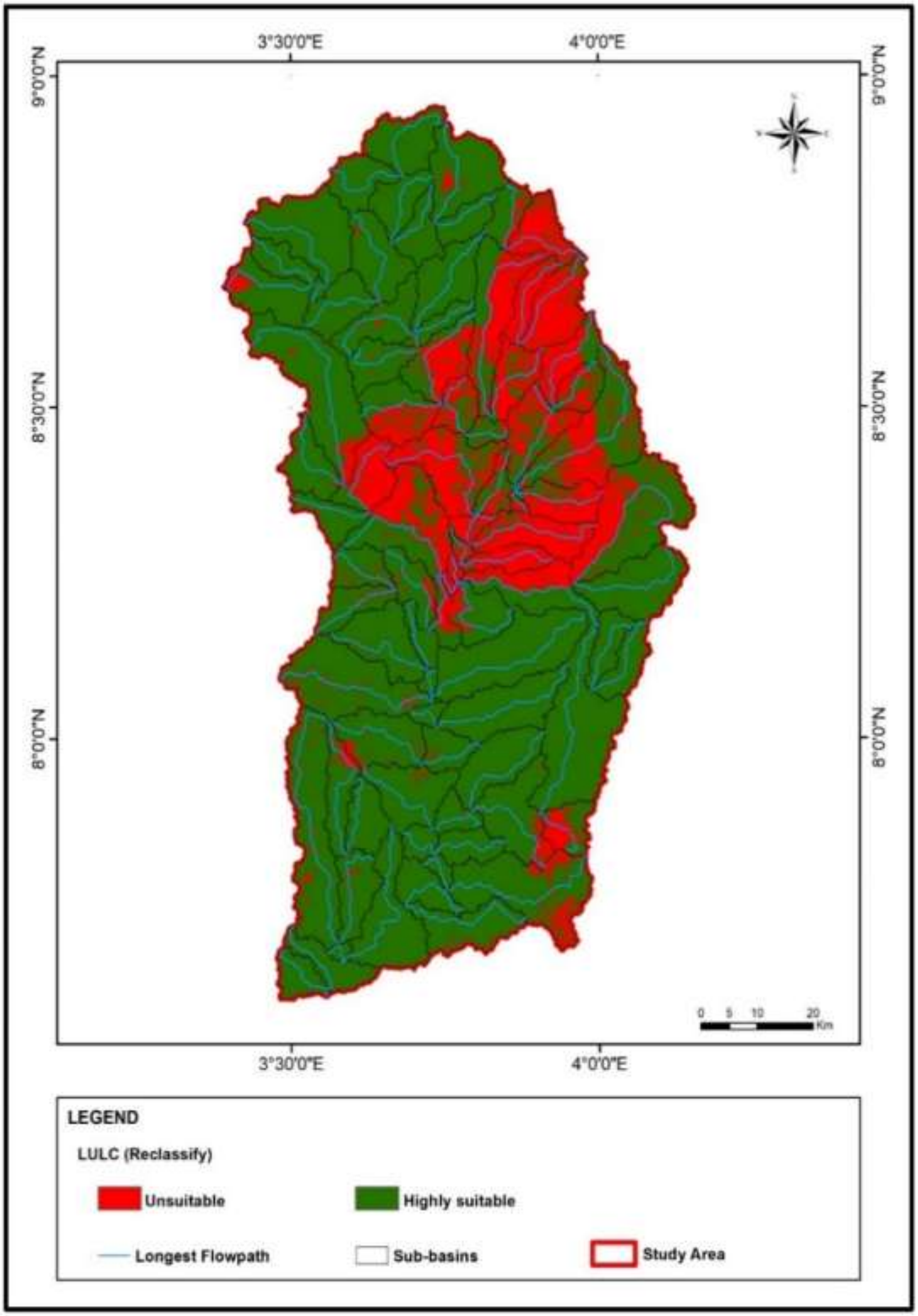

Figure 14. Land Cover/Use Suitability Evaluation Map

Suitable Land for Irrigation Identification

Potential irrigable land was determined by creating irrigation suitability model analysis which involved weighting of values of all data sets such as soil, slope, land cover and proximity to water supply, road, farm settlement and market. Analytical Hierarchical Process (AHP) was adopted as the fundamental scale for pair wise comparison matrix of the elements for the irrigation suitability analysis while the result of this exercise was used for the weighted overlay.

Pair-Wise Comparison Matrix (PCM) For Multi-Criteria Decision

The AHP rating adopted for this exercise is as given in Table 11 while the derived Pair-wise Comparison Matrix (PCM) for multi-criteria decision layers is as given in Table 12.

Table 2. Analytical Hierarchical Process (AHP) Rating

Scale	Degree of preference
1	Equal importance
3	Moderate importance of one factor over another
5	Strong or essential importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Values for inverse comparison

To normalize the pair-wise comparison matrix, the cell values of PCM were divided by the sum of the column to obtain the cell values in NPCM and averaged in row to calculate the weights of criterion. The result of this is presented in Table 13.

Table 12. Pair-wise Comparison Matrix (PCM) for Multi-Criteria Decision Layers

S/N	Factor	Slope	Soil depth	Soil drainage	Soil type	LULC	Distance to road	Distance to river	Soil texture
1	Slope	1.00	3.00	3.00	3.00	5.00	5.00	5.00	7.00
2	Soil depth	0.33	1.00	3.00	0.33	3.00	5.00	5.00	3.00
3	Soil drainage	0.33	0.33	1.00	0.33	3.00	3.00	3.00	5.00
4	Soil type	0.33	3.00	3.00	1.33	5.00	5.00	4.00	9.00
5	LULC	0.20	0.33	0.33	0.20	1.00	3.00	3.00	5.00
6	Distance to road	0.20	0.20	0.33	0.20	0.33	1.00	0.33	3.00
7	Distance to river	0.20	0.20	0.33	0.25	0.33	3.00	1.00	2.00
8	Soil texture	0.14	0.33	0.20	0.11	0.20	0.33	0.50	1.00
	Sum	**2.74**	**8.40**	**11.20**	**5.43**	**17.87**	**25.33**	**21.83**	**35.00**

Table 13. Normalized Pairwise Comparison Matrix (NPCM) for Multi-Criteria Decision

S/N	Factor	Slope	Soil depth	Soil drainage	Soil type	LULC	Distance to road	Distance to river	Soil texture
1	Slope	0.36	0.36	0.27	0.55	0.28	0.20	0.23	0.20
2	Soil depth	0.12	0.12	0.27	0.06	0.17	0.20	0.23	0.09
3	Soil drainage	0.12	0.04	0.09	0.06	0.17	0.12	0.14	0.14
4	Soil type	0.12	0.36	0.27	0.18	0.28	0.20	0.18	0.26
5	LULC	0.07	0.04	0.03	0.04	0.06	0.12	0.14	0.14
6	Distance to road	0.07	0.02	0.03	0.04	0.02	0.04	0.02	0.09
7	Distance to river	0.07	0.02	0.33	0.05	0.02	0.12	0.05	0.06
8	Soil texture	0.05	0.04	0.02	0.01	0.01	0.01	0.02	0.03
	SUM	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Weighted Overlay for Multi-Criteria Decision

The computed weights of the irrigation suitability elements are as presented in Table 14.

Table 14. Weights of the Factors Used for the Analytical Hierarchical Process (AHP)

S/N	Factor	Weight	Weight (%)
1	Slope	0.31	31
2	Soil type	0.23	23
3	Soil depth	0.16	16
4	Soil drainage	0.11	11
5	LULC	0.08	8
6	Distance to river	0.05	5
7	Distance to road	0.04	4
8	Soil texture	0.02	2

The final result of the weighted overlay exercise for the different suitability classes is graphically represented in Figure 15 and the computed quantities is presented in Table 15.

Table 15. Final Result of Surface Irrigation Suitability Evaluation Table

S/N	Surface Water Irrigation Suitability	Area Coverage (Km^2)	Percentage of Total Area (%)
1	Highly suitable	704.9	9.0
2	Moderately Suitable	6162.2	78.9
3	Marginally suitable	947.0	12.1
	Total	**7875.4**	**100.0**

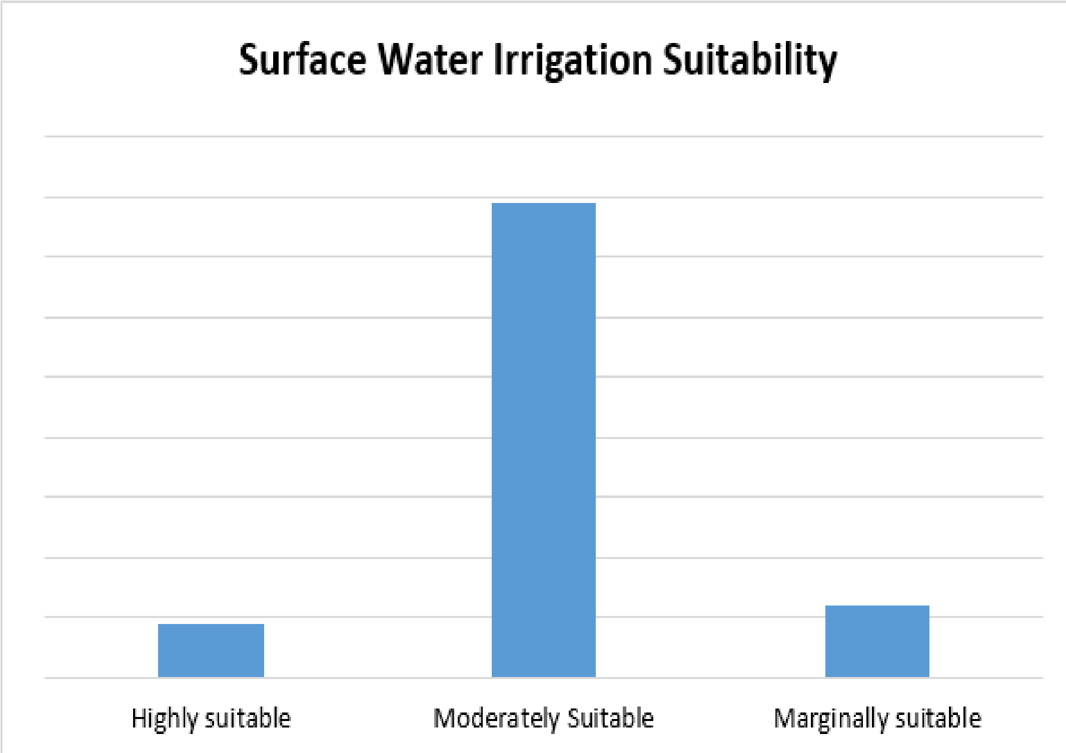

Figure 15. Final Result of Surface Irrigation Suitability Evaluation Bar Chart

Table 15 presents the sizes of the identified irrigable land areas classes. It shows that about 9.0% of the total land areas amounting to 704.9 square kilometers of land fall within the areas classified as highly suitable for surface irrigation. It is also discovered that about 78.9% of the total area covered amounting to approximately 6162.2 square kilometer fall within the area that can be classed as moderately suitable while about 12.1% equating to about 947.0 square kilometers of land is classed as marginally suitable.

Figure 16 shows the identified potential irrigable lands among the main and tributary perennial rivers. The main and tributary rivers are referring to the main and sub-watersheds obtained by watershed delineation in section 3.1. Attempts were made to identify potential reservoir or diversion sites above the identified irrigable areas since the suitability was assessed for surface irrigation methods.

Water Resources Assessment

The hydrological simulation exercise generated a CN grid raster file which graphically illustrate water availability considering all relevant factors in the hydrological process and a database showing the calculated quantities for each sub-basin. The total surface water available for irrigation was calculated to be approximately *eleven billion, one hundred and ninety-four million, two hundred and five thousand, and eighty-seven cubic meters* (11,194,205,087.223m^3). Figure 17 portrays the CN grid map generated for the water resource assessment exercise.

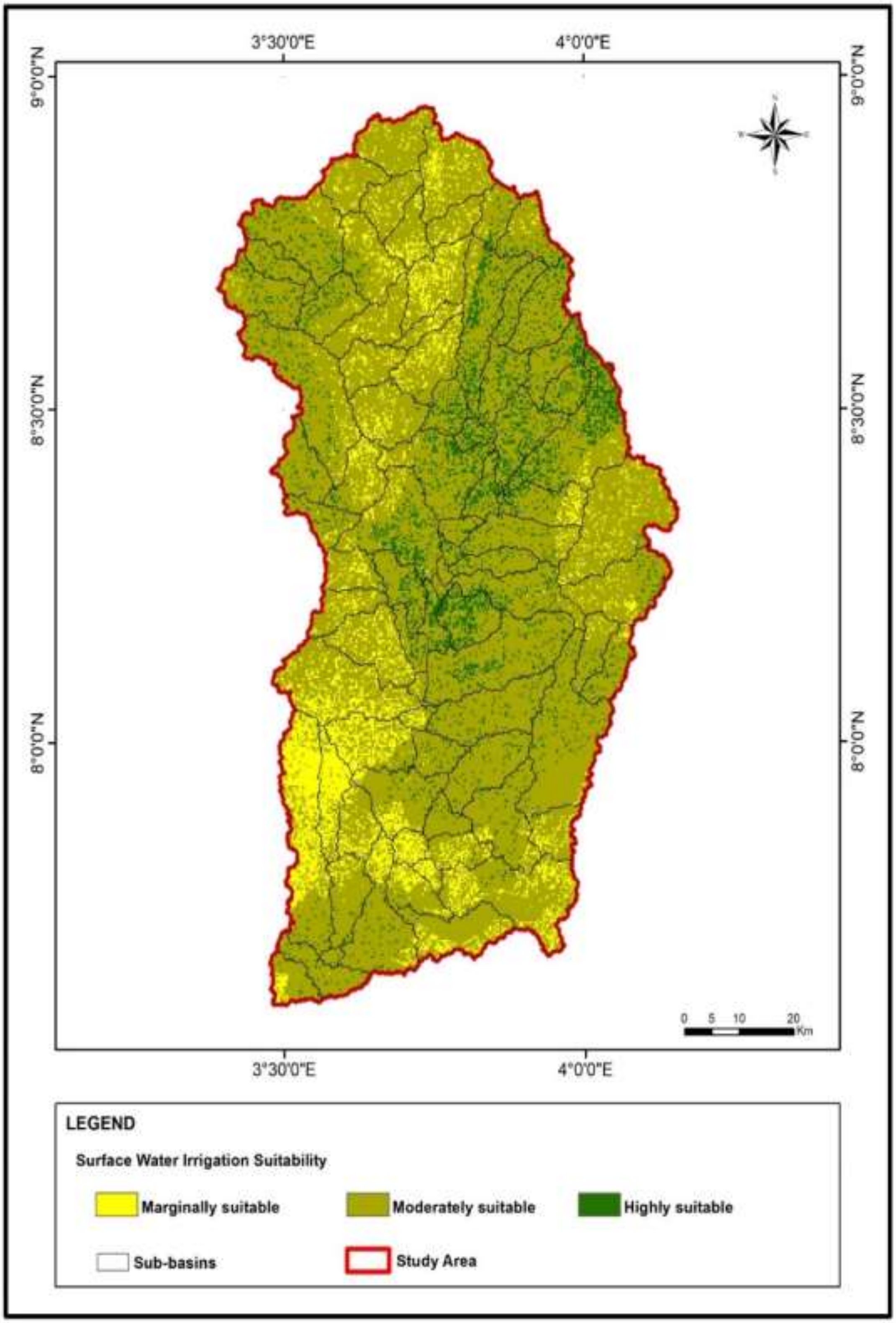

Figure 16. Surface Irrigation Land Suitability Evaluation Map

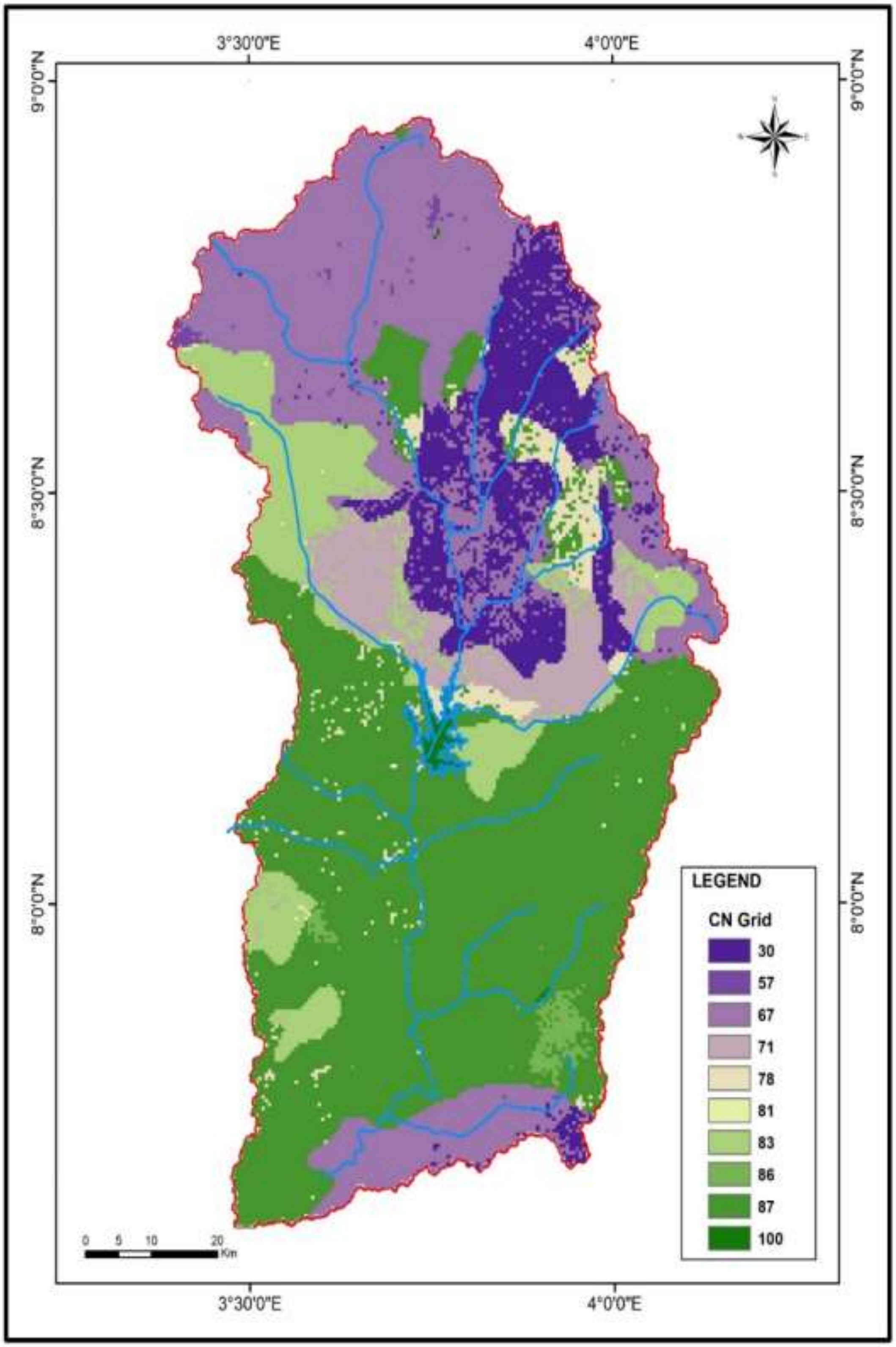

Figure 17. CN Grid for Water Availability Assessment Map

Analysis of Results

Land Cover/Use Accuracy Assessment

Kappa Coefficient statistical analysis was adopted to ascertain the measure of reliability of the classification process. Kappa statistics is a measure of agreement or accuracy between remote sensing-derived classification map and the reference data. The equation for its determination is given as:

$$K = N\sum_{i=1}^{K} Xii - \sum_{i=1}^{K} (x_{i+} * x_{+i})/N^2 - \sum_{i=1}^{K} (x_{i+} * x_{+i})$$

(eqn. 10)

Where:

K = Number of rows

Xii = Number of observations correctly classified for a particular category

Xi+ & X+i = Marginal totals of row & Column i associated with the category

N = Total number of observations in the entire error matrix

Table 16. LULC Accuracy Assessment Table

Class	Waterbody	Built-up Area	Cultivated Area	Forest	Total
Waterbody	6	0	0	0	6
Built-up Area	1	8	2	0	11
Cultivated Area			3	1	4
Forest	0	0	0	9	9
Total	7	8	5	10	30

Precision Accuracy for LULC 2020

Pairwise Weighted Overlay Accuracy Assessment

The consistency of the process was analyzed using the Random Inconsistency Indices scale and applicable mathematical equations given below:

$$CI = (\lambda max-n)/(n-1)$$

(eqn. 11)

Where: n = number of criteria = 8, average CI value = 0.1234

Table 17 Random Inconsistency Indices Table

n	RI
1	0.00
2	0.00
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.46
10	1.49

Source: Random inconsistency indices for n = 10 (Saaty, 1980)

$$Cr = CI/RI = (0.1234/1.41) = 0.0875 \quad \textit{(eqn. 12)}$$

CONCLUSION

This study evaluated the irrigation potential of perennial rivers in the study area mainly Ogun River and its network of feeding upstream system as well as suitability ration of the numerous farm lands within the area of coverage to provide needed information to guide integrated water resource utilization and irrigated agricultural development within the study area. The set objectives of the research were painstakingly pursued adopting the most viable datasets and scientifically efficient methods, and achieved to an acceptable level of accuracies thus making the study a successful endeavour. The total accessible volume of water for surface irrigation within the river catchment was quantified to be 11,194,205,087.223m^3 while approximately 9% of the whole land was identified as suitable for immediate irrigated agricultural development within the catchment and the remaining 90% can be irrigated but after some improvement have been implemented on their current status. Only a very insignificant portion of the whole land was found permanently unsuitable for irrigated agriculture.

RECOMMENDATIONS

Irrigation systems have become an essential investment for improving internally generated revenue through increased agricultural production. However, this can only be accomplished through an integrated assessment of available land and water resources for irrigation. The result of this study can assist in policy decisions during a development of irrigation projects in Upper Ogun River catchments. Products generated such as estimated discharges at pour points**,** identified potential irrigable sites, land cover/use, soil, and slope maps of river catchments can assist state or national planners to facilitate preliminary surveys and prepare irrigation projects in the study area. However, further research is still needed to be pursued on this study in the following areas:

1. The effects of other factors such as water quality, chemical properties of soil, environmental, economic and social terms on irrigation potential need assessment for a more robust result.
2. Land suitability analysis for sprinkler and drip irrigation methods should be carried out to increase the land area suitable for immediate irrigation development.
3. Gauge stations for stream flows measurement should be established within the radius of 50 kilometers all over the country to provide for ground truthing of utilized datasets.
4. Future researches to test other methods such as regional regression analysis, base flow correlation and development of unit hydrograph to estimate discharges at ungauged sites from gauged sites should be done.
5. Adequate documentation of ownership, use and agricultural records (e.g. cropping system, acreage of farmlands, etc.) within the basin should be pursued then water demand/supply ration can be estimated for the dominant cropping systems.

6. Conclusively, future irrigation development projects should explore the capabilities of *RS* and *GIS* for better assessment of land and water resources in this study area and elsewhere.

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