FEDERAL UNIVERSITY OF AGRICULTURE ABEOKUTA NIGERIA

76th INAUGURAL LECTURE

SOIL AND WATER DYNAMICS AS THE ELEVENTH COMMANDMENT

by

Engineer Professor J. K. Adewunmi

(Professor of Soil and Water Engineering)

Department of Agricultural & Bio-Resources Engineering
College of Engineering (COLENG),
Federal University of Agriculture, Abeokuta, Nigeria.

SOIL AND WATER DYNAMICS AS THE ELEVENTH COMMANDMENT

by

Engineer Professor J. K. Adewunmi
Professor of Soil and Water Engineering

Department of Agricultural & Bio-Resources Engineering
College of Engineering (COLENG),
Federal University of Agriculture Abeokuta, Nigeria.

FUNAAB INAUGURAL LECTURE
Series No. 76

Wednesday May 24, 2023

FUNAAB INAUGURAL LECTURE

Series No. 74

by

Engineer Professor J. K. Adewunmi
Professor of Soil and Water Engineering

The 76th Inaugural Lecture was delivered under the Chairmanship

of

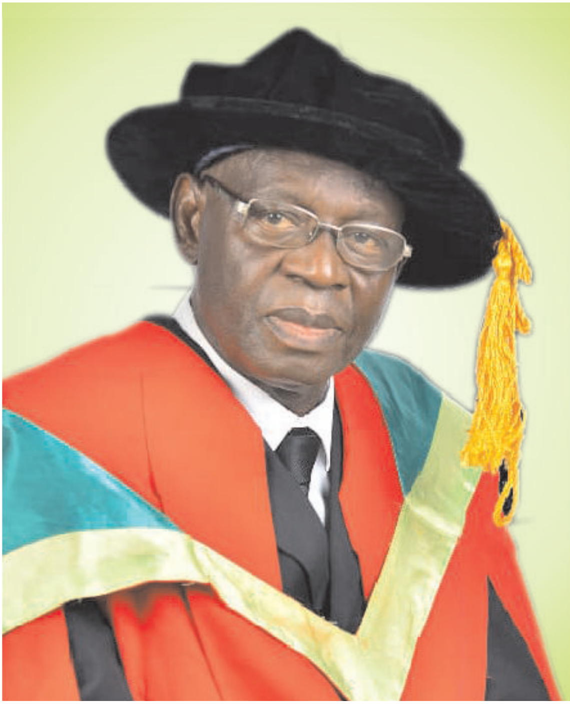
The Vice-Chancellor

Professor Babatunde Kehinde
B.Sc (Agric Biology); M.Sc (Crop Improvement), Ph.D (Ibadan), FGSN, FAIMP, FIHSC

Published Wednesday May 24, 2023

ISBN: 789-789-799-090-2

FUNAAB INAUGURAL LECTURE SERIES



Engineer Professor J. K. Adewumi,
MNIAE, MNSE, R..COREN, C.Eng (UK), IISMCert, (Bet-Dagan, Israel)
(Professor of Soil and Water Engineering)
Department of Agricultural & Bio-Resources Engineering
College of Engineering (COLENG),
Federal University of Agriculture, Abeokuta, Nigeria.

SOIL AND WATER DYNAMICS AS THE ELEVENTH COMMANDMENT

PROTOCOLS

Deputy Vice Chancellor (Administrative),
Deputy Vice Chancellor (Academic),
The Registrar,
The Bursar,
The University Librarian,
Members of the University Governing Council,
Members of the University Senate,
Chief Executives of other Institutions,
My Dean, College of Engineering (COLENG),
Deans of other Colleges, Student Affairs and Postgraduate School,
Directors of Institutes, Centers and Units,
Acting Head of Department of Agricultural & Bioresources Engineering,
Other Heads of Departments,
Academic and Professional Colleagues,
Presidents and Professional Associations,
All Non- Teaching Staff,
Members of my Immediate and Extended families,
Friends and Well Wishers Gentlemen of the Press,
Distinguished Ladies and Gentlemen,
Great ***FUNAABITES***!!!

1.0 INTRODUCTION

This is the 76th Inaugural Lecture in the University and the third in the Department of Agricultural and Bioresources Engineering, the first was delivered by Professor B.A Adewunmi and the second by Professor T.M.A Olayanju.

Soil and water is very vital to life on this green planet earth for supporting both human and animal. The combination of this is what we referred to as Agriculture.

1.1 Agricultural Engineering

Agriculture is the cultivation of soil for production of crops and the rearing of animals for the benefit of man. Engineering is the discipline, art and profession of acquiring and applying scientific, economic, social and practical knowledge to design and build structures, machines, devices, systems, materials and processes for the provision of improvements to the lives and well-being of people. Engineers ensure that efficient and durable versions of the design systems are built. They work with people. They solve technical and social problems through the development of physical systems, processes and the use of modern materials.

Agricultural Engineering, therefore is the discipline that applies all the principles of science and technology to production, processing and storage of food and fiber. Agricultural Engineering combines the disciplines of animal biology, plant biology, mechanical, electrical and chemical engineering principles with the knowledge of agriculture. shows the relationship between Agriculture and Engineering.

1.2 The Past, Present and Future of Agricultural Engineering Profession

The first curriculum in Agricultural Engineering was developed by J. B. Davidson at Iowa State University in 1905. The American Society of Agricultural Engineers (ASAE) now known as American Society of Agricultural and Biological Engineering (ASABE), was founded in 1907. It is an educational and scientific organization dedicated to the advancement of engineering applicable to agricultural, food and biological systems. It has over 10,000 members in more than 100 countries.

The International Commission of Agricultural Engineering (CIGR) was set up by a Constituent Assembly during the first International Congress of Agricultural |Engineering held in Leige, Belgium in 1930. It was an International, Non-governmental, non-profit organizational re-grouping as a network system, regional and National Societies of Agricultural Engineering as well as private companies and individuals all over the world.

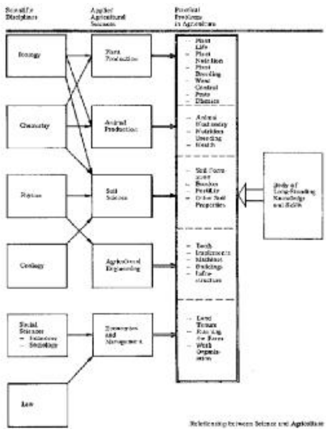


Figure : The relationship between Agriculture and Engineering
Source: www.nzdi.org.

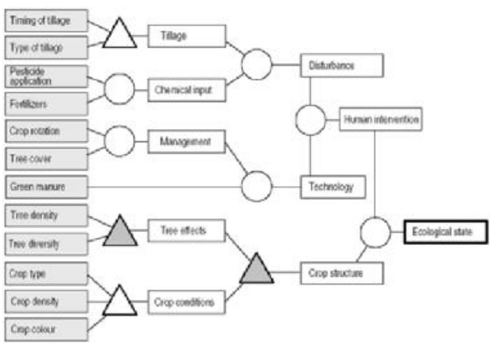


Figure : Importance of Agricultural Engineering in Agriculture Science
Source: www.nzdi.org.

In order to fully cover the scope of Agricultural Engineering, the body of Experts in this field in Nigeria came together and suggested extension to the name of the profession. Among the ones suggested are:

(1) Agricultural and Bio-Resources Engineering
(2) Agricultural and Bio-systems Engineering
(3) Agricultural and Environmental Engineering
(4) Agricultural and Biological Engineering

The Nigerian Society of Agricultural Engineers (NSAE) now called the Nigeria Institution of Agricultural Engineers (NIAE) was founded in 1978. It was one of the most vibrant and active divisions of Nigerian Society of Engineers (NSE). Agricultural Engineering activities involves the following:

(1) Solving problems related to systems, processes and machines that interact with humans, animals, microorganisms, plants, soil and biological materials, design of agricultural machinery and equipment. It also involves crop production including tillage, seeding/planting, irrigation, drainage, and the conservation of life-giving resources such as soil, water, plants and bio-diversities generally.
(2) Devising practical and efficient solutions for producing, storing, transporting and packaging agricultural products such as;
    (a) Animal production, including the care for and processing of poultry, fish and dairy product management.
    (b) Processing of food and other agricultural and bio resources and food engineering
(3) Development of solutions for responsible, alternative uses of agricultural products, by-products, wastes and of our natural resources such as soil, water and energy.
(4) Design of agricultural structures including the improvement of protection of people, animal and

management of the environment.

1.3 Bio-Resources Engineering

This branch of Agricultural Engineering focuses on utilization of technology to connect the living world of plant and animals with the technology of Engineering (systems and machines). Its sphere of influence spans over engineering and environment.

1.3.1 Bio-Resources Engineering covers such functions as:

1. Design, construction and management of technology of food, fiber and energy productions systems: This function dwells on the design and management of machinery for field operations like soil tillage, planting, irrigation, harvesting, storage and handling of agricultural produce.
2. Use precision agriculture technologies such as geographical Information Technology (GIS) and Global Positioning System (GPS) to ensure optimal and sustainable agricultural production systems with minimal impact on the environment.
3. Design and operate transportation systems to move produce to storage facilities and the consumers.
4. Add values to raw products through; design and operation of food processing and storage systems, application of technology to preservation of agricultural produce, ensuring products safety etc.

Agricultural and Bio-Resources Engineering focuses on:

(i) Development of technology for the production, processing and storage of agricultural food and fiber products
(ii) Management of rural economy and technology
(iii) Renewable resources
(iv) Agro-industrial production chains.
(v) Water Resources Development

In all cases, it concerns innovation and sustainable technology.

The interaction between plants, animals, the environment and society play a central role. Development in society often involves the introduction of new technology. The adaptation of new technology and its integration within existing processes therefore requires special attention.
The profession is by far wider than traditional perceptions of agriculture would have one to believe. In fact, Agricultural Engineers often practice well beyond the farm boundary. In areas such as water resources management, forestry, mining and rehabilitation, peri-urban and rural development, machine development and manufacturing.
Combining logic and practical reasoning with inventiveness and innovation, Agricultural Engineering is an interesting, challenging and rewarding profession. It ensures that we have the necessities of life; safe and abundant food to eat, potable water to drink, clean fuel and energy sources and a safe, healthy environment to live in.

1.3.2 The Options

To achieve its objectives, the common options available in Agricultural Engineering profession includes:

(i) Farm Power and machinery Engineering
(ii) Soil and Water Engineering including Land Reclamation & Conservation
(iii) Crop Processing and Storage Engineering
(iv) Farm Structures and Environmental Engineering
(v) Farm Electrification
(vi) Emerging Technologies including Information and Communication Technology (ICT)

1.3.3 Water Aspects

In order to comprehensively assess water management either in agriculture, industry or municipal setting, it is pertinent to put a searchlight on the following broad areas in order to draw inference from previous and current water development efforts.

(i) Integrated water resources management in basins and catchments.
(ii) Institutional frameworks and policy for managing water to meet twin goals of environmental and food security
(iii) Resolution of conflicts between water requirement for agriculture and the desire to meet security and environmental sustainability.
(iv) Water management to sustain fisheries and aquaculture systems
(v) Experience and consequences of prolonged use of groundwater.
(vi) Consideration of rainwater harvesting to support rural livelihoods and food production and in water scarce areas.
(vii) Use of low-quality water in agriculture and waste water agriculture/sewage farming
(viii) Irrigated agricultural development and their benefits, cost and impacts.
(ix) Consequences of land and water degradation on water productivity and on multiple users of water in catchments
(x) Environmental impact of improved water productivity in agriculture especially irrigation
(xi) Drainage (Farm & Urban) and Environmental impact as a result of flooding.

Today, there is an intense competition for water resources in many places. It is widely recognized that many countries are entering an era of severe water shortage and flooding. Can we say that a country is facing water scarcity? At first, it might appear quite simple. Water scarcity is defined in terms of present supply, future demands and needs. Some people gave a benchmark of annual water need to be in the neighborhood of 1700 m^3/per capita/annum; water supply above this level translates to a condition of water sufficiency. However, when water supply falls to as low as 500 m^3/capita per annum, water supply begins to affect, public health, economic growth and general well-being of man. The following statistics present the state of world water:

(i) About 97% of the world's water resource is in the oceans and seas and is too salty for most productive uses.
(ii) Of the 3% available as fresh water, 2/3 of it is locked up in ice caps, glacier, permafrost, swamps and deep aquifers.
(iii) Precipitation accounts for 108,000 km^3 of water annual on the globe. (effect of rainfall)
(iv) Approximately 60% of this i.e., 61000 km^3 evaporates directly back into the atmosphere, leaving 47,000 km^3 as runoff or overland flow towards the sea. (effect of rainfall)
(v) The distribution of this precipitation (rainfall) is equivalent to the availability of 9000m/person/year.
(vi) Much of the flow occurs in seasonal floods as a result of heavy rainstorm
(vii) Estimates indicate the availability or control of between 9000 and 14,000km^3 for use.

In particular region or country, there are four sources of water, i.e.

(i) Inflow from rivers and aquifers minus outflow.
(ii) Changes in storage from stored water in lakes, reservoir, soil moisture, aquifers, snow and ice.
(iii) Runoff (i.e., arithmetic difference between surface and subsurface flow of water). (Excess water on soil surface when the soil has reached a point of saturation after rainfall event).
(iv) Seawater or brackish water.

When water is viewed from the basin perspective, we have to look at water supply and demand not only for all users also at institutional perspectives in the provision of the services. In the past, the focus of the water sector was on individual systems or communities, and in recent times on rural development. Focus has since changed to wider issues of competition for water with emphasis now placed on water of good quality and for agriculture production.

Safeguarding and developing water resources require a combination of inputs or interventions in 3 major dimensions viz;

(a) The upstream-downstream dimension - This recognizes the fact that each water uses or water user potentially impacts on all the other uses and users.

(b) The institutional dimensions - This includes planning, policies, rights, regulations and monitoring and water user's organization. Others are the design and implementation to enhance the effective functioning of organization both at basin and system levels as well as the level of individual uses or users.

(c) Provision of services - This aims at delivering a high and reliable level of service to different water users and for different users in order to encourage productive water use. Other service inputs such as credit, technology and marketing are also to be addressed.

The upstream-downstream dimension works on equitable allocation policy, recognizes existing uses and attempts to reallocate water amongst users to meet emergency needs. Apart from the quantity of water supply, the upstream-downstream dimension also examines the following issues.

(i) Determination of water quality, e.g., from agricultural urban and industrial areas that reduce the value and utility of water to downstream users.

(ii) Safeguards the interest of environmental sensitive areas for adequate water supply (quantity and quality) e.g., wildlife protection, salinity intrusion, etc.

(iii) Risk and opportunities of reuse of waste water for irrigation or consumption.

(iv) Meeting the need of those who have insufficient access to water e.g., the rural poor.

(v) Impact of upstream water harvesting technique in basin-level hydrology.

(vi) Extent to which the exploration and over exploration of ground water resource in the face of reduced availability of surface water affect the basin.

The basin perspective is that improvement of service at a location or for a set of users do not impact on the potentials of water users or uses. The institutional dimension engages both the supplier and users of water at the planning, implementation, regulation and management phases. This is achieved through either a single-purpose line agency or a more comprehensive organization at the basin level which is capable of addressing the complexity of interaction between different uses and users.

Service provision traditionally has been focused on specific use. The general concern is that service must be more effective. Such aspects as power, technology, credit and marketing comes into consideration. Some bodies concerned with water issues in the world identified about four critical areas for water resources management for rural development. They are;

1.4. Four critical areas of Soil & Water in Agricultural Engineering

(i) Groundwater

(ii) Environment and health

(iii) Integrated water management for agriculture and Irrigation

(iv) Smallholder water and land management scheme and Soil Conservation

1.4.1 Groundwater

The argument for groundwater exploration is routed in the following; less capital intensive to develop, largely self-financing, largely private development, not considered, or does not belong to the class of mega-water projects, cheap, convenient and can easily meet individual supplies. It cannot be compared to surface water which is flashy in nature. Nowadays, groundwater development is a slogan frequently used in 'poverty targeting'. Groundwater development has become the central element of livelihood creation programme for the poor. The institutional and technological innovation that has been put to groundwater development in Nigeria is to be addressed in future.

1.4.2. Environmental and health

In most developing countries, Nigeria inclusive, drinking water, hydropower and irrigation facilities are planned and constructed most times without regard to other needs. This is to some extent has been stemmed before project development resulting in a win or lose situation. The disease burden in developing nations is associated with inadequate water both in terms of quantity and quality for domestic use. Added to this is lack of facilities for human, domestic and community wastes in a sanitary manner and generally poor hygienic standards.

In low-income communities, the approach has been to improve water supply through exploration of shallow groundwater with low inefficient technologies. However, falling groundwater levels often lead to drilling of deeper tube wells with more expensive pump requirements.

The groundwater depletion led to shallow water wells in poor communities becoming dry. The generally held opinion is that ground water safe for drinking whereas surface water is not. This opinion is not true for all areas especially in Africa.

1.4.3. Integrated Water Management for Irrigation

For irrigated agriculture to be considered satisfactory, productivity must be high as there must be minimal environmental degradation. The public perception of irrigation still remains dams and canals. There is now a rapid drift of attention from increasing the productivity of land (earlier measured in yield per hectare) to

increasing the productivity of water now measured in yield per water drop) especially in water scarce environment. This means achieving more output per unit of water consumed by agriculture. Productivity gains are achieved through combined effort of agriculturalist and the irrigation engineer.
Another school of thought on this subject advocates the production of food in rain-fed rather than irrigated areas. Only a third of about 1 billion hectares currently under cultivation across the globe is irrigated. In some areas, the average rainfall over the crop season is enough to obtain good yield. However, yields are greatly reduced by short time droughts at critical growth stages. If there is water at the flowering stage. For maize for instance, a 60% reduction in yield could be expected, not minding if water is sufficiently available for the rest of the crop season.

1.4.4. Smallholder Water and Land management Scheme and Soil Conservation

Adoption of technologies such as hand pumps, supplemental irrigation ground water uses and
recharge, rainwater harvesting systems, etc. have greatly improve access to water and made beneficiaries to earn more income. Due to their fragmented nature, water resource institutions have largely failed to provide support for small holder water management schemes. Success had mostly been recorded through initiatives from the smallholders themselves and NGO's.

1.4.5. World Food Challenge

(i) The world population is predicted to grow from 6.9 billion in 2010 to 8.3 billion in 2030 and to 9.1 billion in 2050. By 2030, food demand is predicted to increase by 50% (70% by 2050). The main challenge facing the agricultural sector is not so much growing 70% more food in 40 years, but making 70% more food available on the plate.
(ii) Roughly 30% of the food produced worldwide – about 1.3

billion tons - is lost or wasted every year, which means that the water used to produce it is also wasted**.** Agricultural products move along extensive value chains and pass through many hands – farmers, transporters, store keepers, food processors, shopkeepers and consumers – as it travels from field to fork.

(iii) Producing 1 kilo of rice, for example, requires about 3,500 litres of water, 1 kilo of beef some 15,000 litres, and a cup of coffee about 140 litres. This dietary shift is the greatest to impact on water consumption over the past 30 years.

(iv) In 2008, the surge of food prices has driven110 million people into poverty and added 44 million more to the undernourished. 925 million people go hungry because they cannot afford to pay for it. In developing countries, rising food prices form a major threat to food security, particularly because people spend 50-80% of their income on food.

(v) In developing countries, 43 percent of the farmers are women. Female farmers are considered as efficient as men; however, they do not perform as well because they do not have access to the same inputs, services and productive resources – including water.

(vi) The way that water is managed in agriculture has caused wide-scale changes in ecosystems and undermined the provision of a wide range of ecosystem services. The external cost of the damage to people and ecosystems, and clean-up processes, from the agricultural sector is significant. In the United States of America, for instance, the estimated cost is US$9–20 billion per year.

(vii) Agriculture contributes to climate change through its share of greenhouse gases emissions, which in turn affect the planet's water cycle, adding another layer of uncertainties and risks to food production. It is predicted that South Asia and Southern Africa will be the most vulnerable regions to climate change-related food shortages by 2030.

1.4.6. The Eleventh Commandment

'Thou shalt inherit the Holy Earth as a faithful steward, conserving its resources and productivity from generation to generation. Thou shalt safeguard thy fields from soil erosion, thy living waters from drying up, thy forests from desolation, and protect thy hills from overgrazing by the herds, that thy descendants may have abundance forever. If any shall fail in this stewardship of the land thy fruitful fields shall become sterile stony ground and wasting gullies and thy descendant shall decrease and live in poverty or perish from off the face of the earth."

- Dr.W.K. Lowdermilk on soil Conservation, Jerusalem, 1939

2.0. MY RESEARCH FOCUS

It is divided into three broad areas:

- 2.1 Rainfall Impact on Soil Surfaces
- 2.2 Erosion and Soil Conservation
- 2.3 Irrigation and Food Security

2.1. Rainfall Impact on Soil Surfaces

2.1.1 Rainfall Characteristics and soil tillage timing for Rain fed crop production in the Northern Savanna of Nigeria

Rainfall characteristics and its effect on soil tillage timing for crop production in Samaru-Zaria Nigeria, was investigated. It was observed that soil erosion by water and wind are the major factors degrading soils in the study zone. To manage this occurrence, the rainfall data was obtained from where the storm kinetic energy, intensity and erosion index in Zaria area were computed for 3 years (1995,1996 & 1997) at IAR research field in Samaru- Zaria, to understand the effects of rainfall intensity and other characteristics of rainfall on the soil surface. During the period of the study, intensity of rainfall was very difficult to measure in order to evaluate the kinetic energy on soil surface, I therefore came up with an equation: $I = 3.49e^{0.005KEa}$

Where:
I is intensity of Rainfall in(mm/hr.),
KEa is kinetic energy of rainfall (joules/mm/m^2)
K.E= 14.38InRa-10.43 (J/m^2/mm – Adewumi - 1997) this equation was compared with Kowal and Kassam (Samaru) and Lal 1994 and there was no significant difference. From the above equation, knowing the intensity of rainfall became easier to enable us calculate the (impact) kinetic energy of rainfall on the soil surface.

Similarly, using rainfall data of Samara – Zaria for ten years period, kinetic energy of rainfall as a result of high intensity was evaluated to be K.E=14.38InRa- 10.43(J/m^2/mm) – 1997.
The result was compared with the equation developed by Marshall and Palmer (1948), , Wischmeier and Smith (1965), Hudson (1965), Kowal and Kassam (1976) and Adewumi (1997)

Further research was carried out on the impact of raindrop on soil surface otherwise refered to as soil detachment by raindrop. Detachment means the removal of transportable fragments of materials from soil mass by an eroding agent, usually falling raindrops. The detached particles are transported by two mechanisms, displacement caused by physical impact (i.e plashed) and particle entrainment caused by overland flow. Depending on their size (raindrop) cohesive strength and impact energy, particles splashed into the air to various heights and deposited at some distance from their original location. The mechanism of soil detachment by raindrop is complex and involves changes in energy level of soil water system. For a vegetable cover, the interception by a plant cover reduces the volume and energy of the rainfall reaching the ground surface. This in returns lowers rate of soils erosion. It is also generally accepted that at least for low growing crops, the rate of soil erosion decreases as the canopy of the plant cover increases. Therefore, soil detachment is an important process studies caused by water drops impacting onto the bare soil surface and the vegetative cover.

Table 1: Measurement of rainfall Amount (mm), calculation of Rainfall Intensity (mm/hr.), and computation of Kinetic Energy (J/m^2/mm) using various energy equations.

Rainfall Date Measurement	Rainfall Amount (mm)	Rainfall Intensity (mm/hr)	Marshall & Palmer KE = 8.95 + 8.44LogI (J/m^2/mm)	Wischmeier & Smith KE = 11.87+ 8.73LogI (J/m^2/mm)	Hudson KE = 29.8 – 27.5/I (J/m^2/mm)	Kowal & Kassam KE = 41.1 Ra – 120 (J/m^2/mm)	Adewumi K.E= 14.38InRa-10.43 (J/m^2/mm).
4/7/96	46.0	23.0	20.44	23.76	24.26	39.74	44.63
7/7/96	15.0	18.0	19.55	22.83	22.72	31.58	28.64
16/7/96	12.0	16.0	19.11	22.38	21.83	28.86	25.30
19/7/96/	15.0	45.0	22.90	26.30	26.97	31.58	28.64
1/8/96	4.0	6.86	16.01	19.17	11.21	8.09	9.50
3/8/96	20.0	40.0	22.47	25.86	26.61	34.46	32.65
14/8/96	14.0	10.5	17.57	20.79	17.66	30.79	27.52
17/8/96	39.0	45.0	22.90	26.30	26.97	38.98	42.25
26/8/96	7.0	6.46	15.79	18.94	10.06	20.25	17.55
31/8/96	10.0	8.57	16.82	20.02	14.92	26.29	22.68
1/9/96	20.0	29.27	21.33	24.67	25.44	34.46	32.65
4/9/96	25.0	36.59	22.15	25.57	26.32	36.27	34.02
9/9/96	28.0	21.0	20.11	23.41	23.73	37.07	37.49
15/9/96	2.50	3.0	12.98	16.04	-12.7	-4.21	2.75
18/9/96	5.30	15.9	19.09	22.36	21.78	14.60	13.55
2/10/96	18.0	25.71	20.85	24.18	24.84	33.48	31.13
7/10/96	25.0	41.67	22.62	26.11	26.74	36.27	34.02

Source: Adewumi et.al., 2020

Since the impact of raindrop on the soil surface is the major cause of Erosion in the farmland, investigation was further conducted into the soil erosion (Soil Loss) prediction generally. Not only is the estimation of soil dislodged important, but also the total soil loss after any rainstorm event is equally essential.

Erosion by rainfall is one of the major hazards threatening the productivity of farmlands, therefore during the year 2020, we examined the rate of soil detachment using rainfall simulator if organic mulching was incorporated into the soil here in FUNAAB as most soils in FUNAAB consist of 87% sand as reported by Dada(2014). The study determined the rate of soil detachment under natural rainfall and simulated rainfall for effective soil conservation measure.

Table 2: Detached soil particles from both bare and treated soil under natural rainfall

S/N	Date of rainfall event	Amount of rainfall (mm)	Average soil detached from bare soil (g/m^2)	Average soil detached from treated soil (g/m^2)	Calculated rainfall intensity (mm/hr)	Rainfall kinetic energy (J/m^2/mm)
1	14/05/2016	30.00	9.98	6.90	47.36	38.48
2	18/05/2016	13.10	10.91	8.24	46.24	26.56
3	22/05/2016	32.00	11.54	7.76	73.84	39.41
4	27/05/2016	15.70	12.71	7.86	42.82	29.16
5	2/6/2016	19.60	13.80	8.27	58.80	32.35
6	3/6/2016	12.40	13.32	8.41	74.40	25.77
7	5/11/2016	10.20	10.33	6.83	47.07	22.96
8	11/11/2016	62.40	12.36	7.81	70.64	49.01
9	15/11/2016	12.10	11.16	7.67	48.40	25.22
10	18/11/2016	9.70	10.80	7.71	58.20	22.24
		? = 217.20	? = 116.93	? = 77.51		

Source: Adewumi et. al., 2020

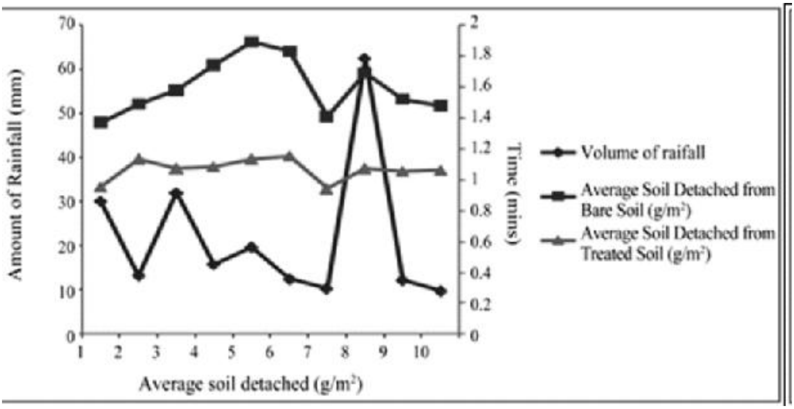


Figure : Relationship between volume of rainfall and average soil detached
Source: Adewumi et. al., 2020

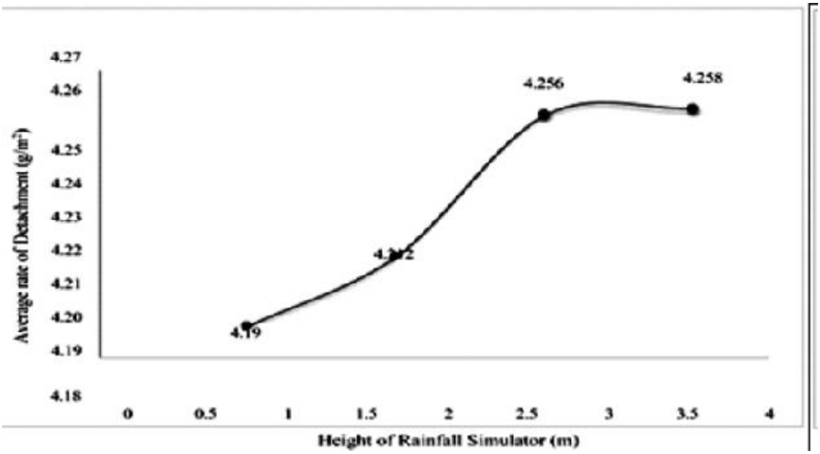


Figure 4 : Soil detached (g/m^2) against the height of simulator (m) (treated).

Source: Adewumi et. al., 2020

The study concluded that raindrops are major cause of soil splash at the earth surface and make the soil loose susceptible easily to soil erosion, understanding the fact that no rainfall events have the same intensity. It was further observed that dislodgment of soil is caused by forces applied on the soil particles by erosive agents, and splash from raindrop impact causes erosion to occur easily implying that both natural rainfall and rainfall simulator observed that the amount of rainfall and its intensity resulted in the amount of soil so detached. The study concluded from the area studied, indicates that the higher the calculated rainfall intensity and rainfall kinetic energy, the greater the amount of soil detached from bare soil. This is similar to the findings of Wilken et. al (2018) where they studied the uncertainties in rainfall kinetic energy intensity relations for soil erosion modeling in four catchment experimental setup areas of NE-Germany. The effect of soil detachment which subsequently leads to erosion was further investigated with detachment equation developed by RPC Morgan (1982) as:

$$DET = K*KE^{1.0}xe^{-bh} \quad (g/m^2) \qquad (2)$$

K = an index of detachability of the soil (g/j) (taken as 0.01)
KE = the total kinetic energy of the rain (J/m^2)
b = an exponent taken as 2.0 and
h = the depth of the surface soil layer (m)
Soil detachability depends on soil texture. Values for the index are given in the Erosion model Use's guide version 2 (1993). They are taken from graphs and tables presented by Poesen (1985), Govers (1992), and Everaert (1992) and corrected according to the procedure proposed by Poesen and Torri (1988) to allow for differences in the size of measuring plots used by the various researchers.

The study concluded that the relationship assumes that soil detachment by rain drop-impact decreases exponentially as the water depth increases. This occurs because the raindrop energy is absorbed by the depth of water instead of the soil surface and because the water layer resists the development of lateral water jet set up within the splash crater.

2.1.2. Soil Loss Tolerance Limit for Effective Conservation Measure in Samaru, Northern Nigeria

Adewumi (2000) worked on the soil loss tolerance limit for effective conservation measure in Samaru-Zaria, Nigeria. Using Universal loss equation (A = 0.25RKLSCP) was used to compute the average annual soil loss and soil loss from erosive storm over 30 years in the study area. The result was used to determine a suitable cropping management and conservation practice factor for the area. It was observed that soil loss in the area was very high. A conservation Practice factor of 0.12 for terracing is most desirable for reducing soil loss to tolerable value in Samaru.

2.1.3. Estimation of infiltration from field – measured sorptivity values

Adewumi and Mudiare (2000) reported an estimation of infiltration from field-measured sorptivity values. The report recognized the fact that soil physical properties vary from location to location even on the same field. Existing model [$\tau = \lambda - 1 + \exp(-\lambda)$]

was used to predict infiltration rate in 4 sites in the study area. They found out that the regression coefficient between the measured and calculated infiltration rates for the sites ranged between -0.25 to 14.4 mm and concluded that the statistical interpretation of the analysis showed that there was no significant difference between the measured and the calculated values of infiltration rates of the sites.

2.1.4 Validation of universal soil loss equation for selected soil locations in North Central Nigeria using a rainfall simulator.

The loss of valuable natural resources of a large area occurs over time which alters soil properties, thus making the land unsuitable for agricultural purposes (Shaxson, 1999; Cervera et al., 2019). Therefore, soil erosion is a generally slight and gradual process as it involves the systematic elimination of the upper layer of soil, including plant nutrients through either water or wind (Bhattacharya et al., 2016; Poesen, 2018; Nwagwu et al., 2018). For years, Nigeria has faced many environmental threats (Oni, 2011; Ogwo et al., 2012; Olagunju et al., 2015), including soil degradation through surface runoff generation. Soil loss renders many agricultural lands unproductive for farmers. According to Ufoegbune et al. (2011) and Polykretis et al. (2020), soil loss estimation takes a lot of time and is capital intensive.

2.1.5. Concept of Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation (USLE) of Wischmeier and Smith (1987) quantifies soil erosion as the spatial and temporal average soil loss per unit area, and this is based on the product of six factors; rainfall and run-off erosivity (R), soil erodibility (K), slope length (L), slope steepness/gradient (S), crop management (C) and conservation support practice (P). The equation is thus:

$$A = RKLSCP \tag{3}$$

Where, A is expressed in tons per ha per year (t ha^{-1} yr^{-1}), R is the summed erosive potential of rainfall events yearly (MJ mm ha^{-1} h^{-1} yr^{-1}), K expresses Erodibility of soil loss per unit of rainfall erosivity (Mg ha h ha^{-1} MJ^{-1} mm^{-1}), L, S, C and P are all dimensionless.

Kinnell (2011) did further state that USLE was designed to predict sheet and rill erosion from a field-sized area with only rainfall erosivity R and soil erodibility K. He further stated that the value of the L, S, C and P factors should not exceed the value of 1.0 for the bare fallow area of 22.1 m length field with a slope of not more than 9%. Thus, soil loss for the unit plot was given by equations and

$$A_1 = RK \qquad (4)$$

While for varied sizes of slope length, crop management and conservation practice

$$A = A_1 LSCP \qquad (5)$$

Where A_1 is the product of R and K (L= S = C = P = 1.0)

The level of soil detachment against the experimental runs at a minimum and maximum intensity, are presented in Figures 6 and 7, respectively. Soil detachment from the bare plot at both positions exceeded soil detachment from vegetative plots, with soil detachment at a maximum intensity from bare and vegetative plots having higher yields than soil detachment at a minimum level from bare and vegetative plots. This result confirms the importance of crop cover in reducing the effects of the direct impact of water drops leading to water erosion. It was also observed that the graphical pattern of both and were not of specific concern during the experimental runs, which indicate considerations of other factors such as the interacting effect of raindrop and surface crusting (Adewumi, 2019). It was observed that there was a weak correlation between soil detachment from bare soil at the concentration ($p>0.05$, $R^2 = 0.6354$) and regression between soil detachment from vegetative and bare soil at maximum intensity ($p<0.05$, $R^2 = 0.92$) as presented in .

Table 3: Results of linear regression analysis (soil detachment)

Eq	R^2	Significant Level
$SDV_{min} = -0.3368KE^3 + 23.298KE^2 - 537.08KE + 4126.2$	0.21	p>0.05
$SDB_{min} = 3.8999KE^2 - 177.47KE + 2019.4$	0.64	p>0.05
$SDV_{max} = 9.4209KE^2 - 492.37KE + 6433.4$	0.38	p>0.05
$SDB_{max} = 15.601KE^2 - 815.73KE + 10664$	0.32	p>0.05
$SDV_{min} = -0.1792SDBmin^3 + 0.8611SDBmin^2 - 1.1405SDBmin$	0.49	p>0.05
$SDV_{max} = -0.5473SDBmax^3 + 0.3915SDBmax^2 - 1.5088SDB$	0.92	p<0.05

Where KE = Kinetic energy of raindrop, SDVmin = Soil detachment from the vegetative plot at minimum intensity, SDVmax = Soil detachment from the vegetative plot at maximum intensity, SDBmin = Soil detachment from the bare plot at minimum intensity and SDBmax = Soil detachment from the bare plot at maximum intensity.

Musa et. al., 2021

Model Validation

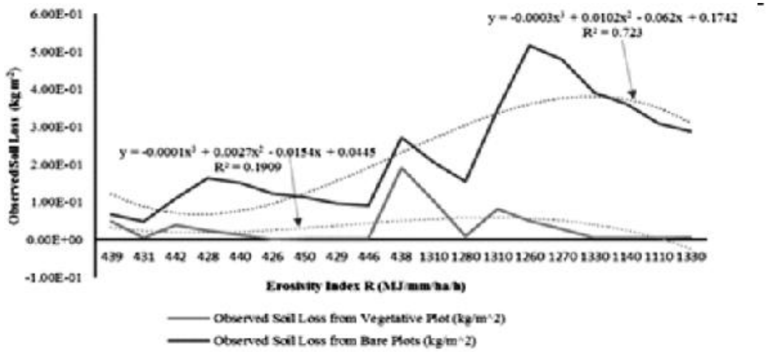


Figure 5 : Graph of observed soil loss against the erosivity index
Musa et. al., 2021

A greatly reduced coefficient of determination for vegetative plot (R^2= 0.190) was observed in indicating that rainfall erosivity was not a good estimator for short term rainfall events for vegetative plot with the rainfall simulator but on the other hand, the rainfall erosivity did characterize the erosive action of the rainfall simulator and supported the validity of the USLE for the study area on a short term given the high coefficient of determination for bare plot (R^2 = 0.723). There was a spike in the observed soil loss data reading when erosivity index value attained 446 MJ/mm/ha/h especially for the vegetative plot which suggests that this could be the threshold value of erosivity index in this location.

Figure 7 shows the observed soil loss against the erosivity index. The coefficient of determination for vegetative plot (R^2= 0.10) and bare plot (R^2= 0.61) for erosivity index is lesser than the estimated threshold of 446 MJ/mm/ha/h, but the values are reduced in Figure 7. The coefficient of determination for vegetative plot (R^2= 0.46) having a greater reduction as compared to bare plot (R^2= 0.78) for erosivity index greater than 446 MJ/ mm/ ha/h. This is because as more raindrops fall more soil particles are detached and eroded until the point where the soil moisture must have reached saturation level with ponding on the surface. The kinetic energy to detach soil particles tend to be constant as the ponding would absorb any energy upon impact.

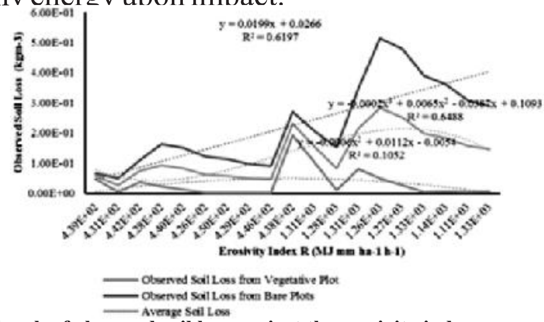


Figure 6 : Graph of observed soil loss against the erosivity index
Musa et. al., 2021

The research validated the Universal Soil Loss Equation for a selected location in North Central Nigeria for both bare plot and vegetative plot using a rainfall simulator. There was a strong correlation over a short term between erosivity index, R, and observed soil losses from bare plots and a combination of both plots but not for vegetative plot over a short-term rainfall event.

2.1.6. Analysis of Soil Water Dynamics in a Tropical Rain Forest Soil (Arinic lixisol), Abeokuta, Nigeria.

Soil water dynamics in the dominant Iwo soil series (Arinic lixisol) were evaluated at the Federal University of Agriculture, Alabata, Abeokuta, Nigeria. Field capacity, infiltration and water retention characteristics were evaluated in situ for a period of 161 d in the dry season for two root zone depths. Results show that the Iwo soil series has a field capacity ranging from 2.6%-5.5% at 0-45 cm and 45-90 cm root zone depths, respectively. A multivariate model relating soil moisture content with soilmoisture tension and soil temperature calibrated within the study had very low model accuracy of 56%and 45% for the two root zone depths, respectively, implying the need for further studies.

Crop growth depends on the use of two important natural resources, soil and water. The effective management of these resources for crop production requires the understanding of the relationships among soil, water, and plants. Soil particles have dominant influence on heat, water, and chemical transport and retention processes in the soil Cultivated crops require certain amount of water at some fixed time interval of its period of growth The availability of this water depends on the soil physical composition, infiltration characteristics and the prevalent climatic condition. Infiltration rate for example is affected by factors such as initial soil moisture content, elapsed time during wetting, soil surface conditions and rate of application

The design of an efficient irrigation and soil drainage system for increased crop production requires the understanding of the dynamics of soil moisture and its availability for crop growth and development. Crop production in South West Nigeria had been predominantly rain-fed, the wide spread non-adoption of irrigation by peasant farmers in the area had been due to the reliance on 8-9 months of rainfall in the past; the area is now experiencing appreciable rainfall for an average of 6-7 months at present due to climate change

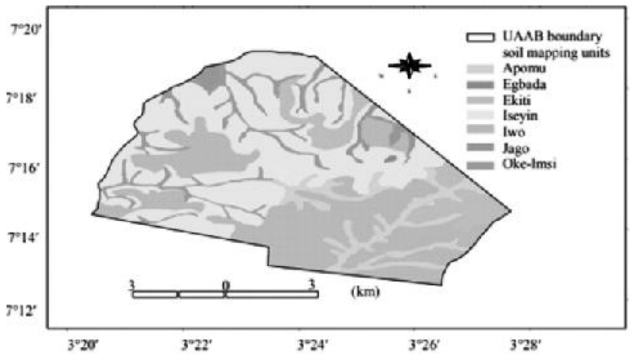


Figure 7: Analysis of Soil Water Dynamics in a Tropical Rain Forest Soil (Arinic lixisol), Abeokuta, Nigeria
Source: Sobowale, et.al., 2014

Table 4 : Selected physical characteristics down the profile of the Iwo soil series

Soil depth (cm)	Soil texture	Mean bulk density (g/cm^3)	Mean particle density (g/cm^3)	Porosity	Void ratio
0-45	Sandy	1.52	1.80	0.16	0.19
45-90	Gravelly sand	1.74	2.05	0.15	0.18

Source: field survey

The soil at the experimental site was found to be predominantly sandy with increasing gravel content down the soil profile. Table 1 presents some selected physical characteristics of the Iwo soil series at the study site. The mean antecedent soil moisture content before the commencement of infiltration test at 0-45 cm and 45-90 cm root zone depths was 3.9% and 5.5%, respectively, indicating that the area is presently in the dry season. Water infiltration was found to increase sharply with time in the early stages of the test; but steady state condition was achieved after 25 min.

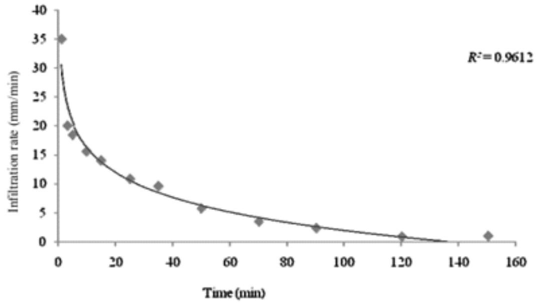


Figure 8 : Infiltration characteristics of Iwo soil series at Alabata, Abeokuta
Source: Sobowale, et.al., 2014

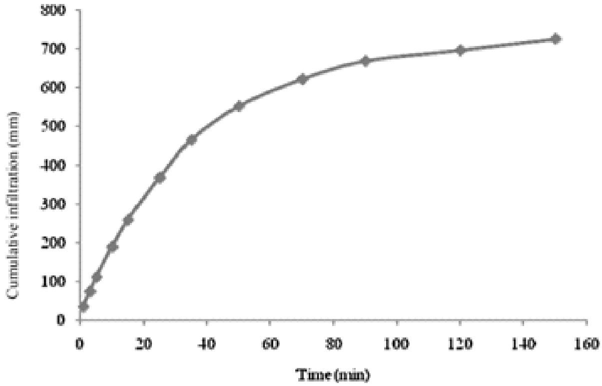


Figure 9 : Cumulative infiltration characteristics of Iwo soil series at Alabata, Abeokuta
Source: Sobowale, et.al., 2014

An excellent fit was obtained with logarithmic model with 96% model accuracy as follows:

$$I = -6.2In(t) + 31 \qquad (6)$$

Analysis for field capacity at the test site after 72 h of gravitational drainage revealed soil moisture content of 2.6% for 0-45 cm root zone depth, and 5.5% for 45-90 cm root zone depth. This is also an indication that the first root zone depth will support shallow rooted crops but will require frequent irrigation while the second root zone will require less frequent irrigation. The result obtained agrees with that reported by Brady and Weil (2008) and Gijsman et al. (2002) for predominantly sandy soils. Available water for plant growth in sandy soil ranges between 2%-8%; hence, maintaining the soil at this moisture status will require a very short irrigation interval of about 2-3 mm in sandy soils especially the Iwo soil series.

The multivariate regression analysis gave multiple R statistics of 0.75 and 0.67 for the root zone depth 0-45 cm and 45-90 cm, respectively. The model equation that best describe the relationship between the three variables at 0-45 cm root zone depth is stated in Eq. (7)

$$? = 3.8152 - 0.011? + 0.0122? \qquad (7)$$

where, θ is the soil moisture content (%), Ψ is the soil moisture tension (cb), and T is the soil temperature (°C). The model equation obtained for the 45-90 cm root zone depth is given in Eq. (8)

$$? = 14.982 + 0.01792? - 0.4181? \qquad (8)$$

The soil is quick draining with high infiltration rate and very poor water retention capacity confirming that the soil will require a short irrigation interval of about 2-3 d since available water for plant growth in predominantly sandy soils ranges between 2%-8%. Based on the foregoing, sprinkler irrigation is best suited for the Iwo soil series, it should, however, be noted that the water application rate must be less than the infiltration rate of the soil in order to prevent surface ponding and runoff.

2.2 Erosion and Soil Conservation

2.2.1. Soil Erosion Prediction in Samaru-Zaria: Comparision of two Predictive Models.

In order to accurately predict amount of soil loss in any rainfall event, two erosion models developed by USA called WEPP (Water Erosion Prediction Project) and the Model developed by

EUROPEAN Countries called EUROSEM (European Soil Erosion Model) was investigated using parameter within the Northern Guinea Savanna zone of the country because the weather system over Samaru-Zaria which was described as being distinct and consistent over several decades (Kowal and Knabe, 1972) shows that there are two major factors responsible for soil Erosion and soil loss in our land namely:

(1) the rainfall amount and impact on the soil surface and
(2) The soil characteristics.

Two models were subjected to our Nigeria climatic data. At the end of three years of study, EUROSEM was best fit to the climate of Northern Guinea savanna zone.

The first model referred to as Model1 computes soil loss as sediment discharged, defined as the product of the volume of runoff (m^3/s) and the sediment concentration in the flow (m^3/m^3). The computation is based on the dynamic mass balance equation. (Bennett, 1974: Kirkby, 1980).

2.2.1.1. European Soil Erosion Model (Eurosem) Model 1

The model computes soil loss as a sediment discharge defined as the product of the volume of runoff
(m^3/s) and the sediment concentration in the flow (m^3/m^3), to give a volume (or mass) of a sediment passing a given point in a given time. The computation is based on the dynamic mass balance equation (Bennett, 1974; Kirkby, 1980)

$$a_s \; x, t \; = \frac{\delta(AC)}{(AC)} + \frac{\delta(OC)}{} - \; e[x, t] \qquad (9)$$

Where,
C = sediment concentration (m3/m3)
A = Cross sectional area of the flow (m2)
Q = Discharge (m3/s)
q_s = external input or extraction of sediment per unit length of flow (m3/s/cm)
c = net detachment rate or rate of erosion of the bed per unit length of flow (g/s/m2)
x = horizontal distance, and
t = time (mins)
The term C is defined by two major components:

c=DET+DF (10)

Where DET is the rate of soil particle detachment by raindrop impact ($g/s/m^2$)
DF is the balance between the rate of soil particle detachment by the flow and the deposition rate of sediment in the flow ($g/s/m^2$).
In solving the equation for the soil erosion, the parameters needed include: rainfall interception by vegetation, soil infiltration rate, soil surface conditions and surface runoff.

2.2.1.2. Water Erosion Prediction Project (Wepp): Model 2

Water Erosion Prediction Project (WEPP) represents an advance on CREAMS as it has replaced the USLE relationship for modelling soil erodibility and crop management with more dynamic day field operations as they affect crop canopy cover, crop residue and surface roughness. WEPP contains a dynamic water balance calculator which is driven by separate sub-models dealing with climate, crop growth and crop residue decay. Details of the equation used in WEPP are also presented below.
The WEPP erosion model computes estimate of net detachment and

deposition using a steady state sediment continuity equation which is

$$\frac{ds}{dx} = Df + Di \qquad (11)$$

Where:
X = distance downslope (m)
S = sediment load (kg/s/m)
Di = interill erosion rate (kg/s/m^2)
Df = rill erosion rate (kg/s/m^2)
Net soil detachment in rills is calculated for the case when hydraulic shear stress exceeds the critical shear stress of the soil and when sediment load is less than sediment transport capacity. Therefore

$$Df = Dc\ [1- S/Tc] \qquad (12)$$

Where Dc = detachment capacity by flow (kg/s/m2) and
Tcis thesediment transport capacity in rill (kg/s/m2) =
=2.67+0.065 CLAY-0.058VFS
When hydraulic shear stress exceeds critical shear stress for the soil, detachment capacity, Dc is expressed as:

$$Dc = K_f\ (\mathcal{T}f - \mathcal{T}c\ ) \qquad (13)$$

Kf is a rill soil erodibility parameter (s/m)
$\mathcal{T}f$ is the flow shear stress acting on the soil (Pa)
$\mathcal{T}c$ is the rill detachment threshold parameter of critical shear stress of the soil(Pa)
Where VFS is the percent very fine sand (%)
CLAY is the percent Clay (%)
The equations above are for soils containing 30% or more of sand. The rill soil erodibility parameter can be estimated as:

$$K_f = 0.00197 + 0.00030*VFS + 0.03863\exp(-1.84*ORGMAT) \qquad (14)$$

Where
ORGMAT is the percent organic matter in the surface soil (and

the model assumes that organic matter equals 1.724 times organic carbon content.

$$K_f = 2728000 + 192100VFS \quad (15)$$

The parameters stated in both EUROSEM and WEPP equations above were measured in experimental plot in Samaru, Zaria as input into the models.

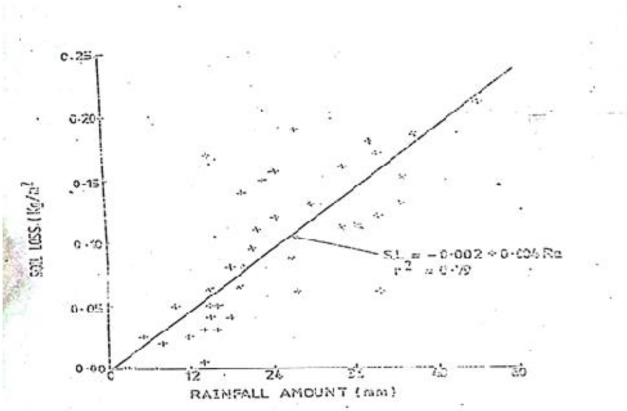


Figure 10 : Relationship between Observed Soil Loss and Rainfall Amount
Source: Adewumi et. al., 2001

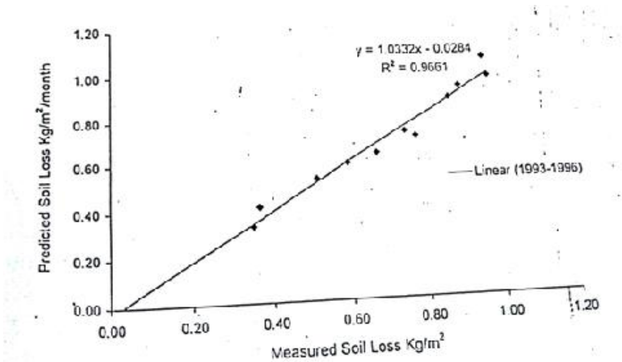


Figure 11 : Predicted Vs. Measured soil loss (Bare Soil Model 1)
Source: Adewumi et. al., 2001

It was observed that the relationship between measured soil loss (S.L.) and rainfall amount (Ra) in Figure 10was obtained as

S.L=-0.002+0.004Ra (6)

Where S.L is the soil loss in kg/m2

Ra is the Rainfall amount per storm (mm)

For Bare Soil,

Y=0.028+1.03X (7)

For model 1, r =0.98

Y= -3.45+10.64X (8)

For model 2, r = 0.45

Where Y is Predicted Soil loss in Kg/m2 and

X is the Measured Soil Loss (kg/m2)

2.2.2. Evaluation of Soil Erodibilty Indices

Musa and Adewumi (2018) Evaluated the Erodibility property of Southern Guinea Savanna Ecological zone of Nigeria, and reported that ability of the soil to withstand erosive power of rainfall depends on various factor - soil textures, aggregates, stability, shear strength, soil structures, infiltration capacity, soil depth, bulk density, soil organic matter and chemical constituents. Soil erodibility is an estimate of the ability of soil to resist erosion based on the physical characteristics of each soil. Generally soils with faster infiltration rates, higher levels of organic matter and improved structure have a greater resistance to erosion (Dexter, 2004). A soil with relatively low erodibility factor may show signs of serious erosion, yet a soil could be highly erodible and surfed little erosion, this is because soil erosion is a function of many factors as stated in the Universal Soil Loss Equation (USLE). These factors include rainfall factor (R), soil erodibility factor (K), slope length (LS), crop factor (C) and control practice factor (P) with respect to the area. This is represented in the Universal soil loss equation as ?? = ???????????1 Erodibility is the resistance of the soil to both detachment and transport (Emeka, 2014). The soil erodibility factor K is aquantitative expression of the inherent

susceptibility of a particular soil to erode at different rates when the other factors that affect erosion are kept constant (Ezeabasili1 et al., 2014). Erodibility varies with soil textures, aggregates, stability, shear strength, soil structures, infiltration capacity, soil depth, bulk density, soil organic matter and chemical constituents.
Soil is a complex mixture of minerals, water, air organic matter, gases, liquids and the countless organisms that are decaying remains of once living things (Schoonover and Crim, 2015). It forms at the surface of land, thus it is referred to as the skin of the earth. Soil is capable of supporting plant life and it is vital to life on earth. A good soil for growing most plants should have about 45% minerals (with a mixture of sand, silt and clay), 5% organic matter, 25 air, 25% water (Saxton and Rawls, 2005).

Table 5: Location of the various sample points

Location	Longitude	Latitude
A	006^0 26.499''E	090^0 31.126''N
B	006^0 26.546E''	009^0 33.128''N
C	006^0 27.521''E	009^0 32.139''N
D	006^0 27.821^0E	090^0 33.189''N
E	006^0 24.411^0E	090^0 30.316^0N

Source: Musa and Adewumi 2018

Table 6 : Result of statistical analysis

Samples	MC	BD	PD	Porosity	Organic Matter
Plot A	9.07 ± 0.07^{d}	1.08 ± 0.45^{b}	1.52 ± 0.31^{a}	58.67 ± 1.53^{a}	4.033 ± 0.51^{a}
Plot B	8.51 ± 0.26^{bc}	0.93 ± 0.52^{a}	1.65 ± 0.14^{a}	64.00 ± 2.00^{b}	3.77 ± 0.25^{a}
Plot C	8.28 ± 0.39^{ab}	0.95 ± 0.79^{a}	1.41 ± 0.03^{a}	63.33 ± 3.06^{b}	4.17 ± 0.35^{a}
Plot D	7.95 ± 0.28^{a}	0.94 ± 0.36^{a}	1.41 ± 0.12^{a}	63.67 ± 1.52^{b}	3.72 ± 0.22^{a}
Plot E	8.9 ± 0.17^{cd}	0.90 ± 0.22^{a}	1.33 ± 0.96^{a}	65.33 ± 1.15^{b}	3.82 ± 0.42^{a}

Means± standard deviation with the same letters in a column are not significantly different at 50% level of probability. Where a and b represent no significant difference (NS), ab, bc and cd represents Least significant difference (LSD) in the data.

Source: Musa and Adewumi 2018

Table 7: Erodibility index of selected plots

Plots	Samples	Depth (cm)	Erodibility index (K)
A	1	0-10	-71.14
	2	10-20	-80.58
	3	20-30	-83.22
B	1	0-10	-79.68
	2	10-20	-80.84
	3	20-30	-85.12
C	1	0-10	-72.98
	2	10-20	-81.26
	3	20-30	-74.82
D	1	0-10	-85.61
	2	10-20	-79.93
	3	20-30	-85.24
E	1	0-10	-77.75
	2	10-20	-82.83
	3	20-30	-87.32

Source: Musa and Adewumi 2018

The effect of erodibility index of the selected soils showed that the rate of permeability of water into the soil was relatively fast at the initial stage and after a few minutes, limited rate of water permeability was observed. The soil physical properties had significant effect on the erodibility parameters of the soil to a large extent as most of the soils were sandy loam in nature. The results further shows that the particle size analysis soils in the study area are mainly Sandy loam which makes them less susceptible to erosion as the rate of permeability of water into the soil is slow. It is therefore concluded that the soil within the study area have poor erodibility indices as a result of their poor permeability rate. This leads to the ponding of water in the study area and later, the occurrence of an almost surface runoff during which fine soil particles are carried away as a result of the movement of water across the soil surface which invariably causes erodibility of the soil.

2.2.3. Rainfall-Runoff

2.2.3.1. Comparing Developed Manning Coefficients for Some Selected Soils of Gidan Kwano with Exiting Values.

Collapse and failure in infrastructures in Nigeria has been a concern to the hydrologist community in Nigeria. Hence the need to determine Manning coefficient for some selected types of soil.

Times of concentration for the five plots were determined using five empirical equations. The results shows that the soil samples of the study area are sandy, sandy loam, clay loam, sandy clay and loamy soils. Time of concentration ranged between 14 and 27 minutes, 49.01 and 52.14 minutes and 11.17 and 6.18 minutes for SCS, FAA and time lag equations respectively. The n values obtained ranged between 0.68 to 3.70, 7.64 to 8.87 and 0.00 to 0.37 for SCS, FAA and time lag values of time of concentration. It can be concluded that the calculated Manning and runoff coefficients for the study area which is higher than the existing one should be used in the design calculation of structures.

The dynamics in soil types in Nigeria are fast changing in the face of urban sprawl and urban consolidation. Development in Nigeria has observed swamp lands into various forms of irrigation farms where concretes of waterway structures are developed to convey water to various farm plots. Increased social awareness of the need to protect and

manage our water resources has also had a significant impact in highly urbanized catchments. Residents are encouraged to employ best management practices (e.g., rain gardens, rainwater tanks etc.).
Quantitatively describing the rate and path of movement of a rain droplet after it strikes the ground surface is essential for the rational development and efficient utilization of our nation's water resources.

The Manning formula, known also as the Gauckler–Manning formula, or Gauckler– Manning–Strickler formula in Europe, is an empirical formula for open channel flow, or freesurface flow driven by gravity. The Gauckler–Manning formula states: ?

$$V=\frac{k}{h}R_h^{2/3}S^{1/2} \qquad (9)$$

where **V** is the cross-sectional average velocity (ft/s, m/s), **k** is a conversion constant equal to 1.486 for U.S. customary units or 1.0 for SI units **n** is the Gauckler–Manning coefficient (independent of units), $\mathbf{R_h}$ = is the hydraulic radius (ft, m) and **S** is the slope of the water surface or the linear hydraulic head loss (ft/ft, m/m) (S = hf/L). The discharge formula, **Q = A V**, can be used to manipulate Gauckler–Manning's equation by substitution for V. Solving for Q then allows an estimate of the volumetric flow rate (discharge) without knowing the limiting or actual flow velocity. The Gauckler–Manning formula is used to estimate flow in open channel situations where it is not practical to construct a weir or flume to measure flow with greater accuracy.

Figure 12 : Study site of map of Minna Extracted from map of Niger State and that of Nigeria
Musa and Adewumi 2018

Table 8: Various equations considered for the estimate of time of concentration

S/No	Method/Equations	Equation in SI units
1	Kirpich	$T_c = 0.0078\frac{L^{0.77}}{S^{0.385}}$
2	Bransby Williams	$T_c = 21.3\frac{L}{5280A^{0.1}S^{0.2}}$
3	Soil Conservation Service (SCS)	$T_c = 0.00526L^{0.8}\left(\frac{1000}{CN}-9\right)^{0.7}S^{-0.5}$
4	FAA	$T_c = \frac{1.8(1.1-C)L^{0.5}}{S^{0.33}}$
5	NRCS Time Lag	$T_L = \frac{2.587L^{0.8}\left(\frac{1000}{CN-9}\right)^{0.7}}{S^{0.5}}$ but $T_c = \frac{T_L}{0.6}$

These equations were selected based on the availability of the various watershed parameters in duplicating local hydrologic estimates. Some of the parameters considered include watershed drainage area, channel length, watershed or channel slope, and watershed shape parameters. These parameters can be difficult and time consuming to estimate. Table 13 shows the System International (SI) units of the various equations considered.

Table 9: Calculated time of concentration for various condition of soil using various equations

S/no	Type of soil	Soil Condition	Kirpich Equation (mins)	Bransbey Williams Equation (mins)	SCS Equation (mins)	FAA Equation (mins)	Time Lag Equation (mins)
1	Sandy	Undisturbed	50	43.06	27	52.14	11.09
		Disturbed	50	43.06	26	51.33	10.77
2	Sandy Loam	Undisturbed	50	43.06	20	51.14	8.04
		Disturbed	50	43.06	23	50.12	9.52
3	Clay	Undisturbed	50	43.06	14	49.01	5.78
		Disturbed	50	43.06	16	51.03	6.62
4	Loam	Undisturbed	50	43.06	16	51.03	11.09
		Disturbed	50	43.06	18	49.01	10.77
5	Sandy Clay	Undisturbed	50	43.06	20	51.34	8.04
		Disturbed	50	43.06	23	50.33	9.52

Source: Musa et. al., 2013

It was observed from Table 13 that Kirpich and Bransbey Williams' equations had fixed values of 50 and 43.06 minutes respectively which is not a good representation of the various types of soils existing within the study area. The Soil Conservation Service (SCS) equation calculated the time of concentration to range between 14 and 27 minutes which had as one of its parameters the curve number. The curve number is the parameter used by the equation to estimate the potential maximum retention of rainfall which will result in direct runoff. The curve number depends mainly on the type of soil, land use and antecedent moisture conditions.

Using the various calculated values of time of concentration for the various equations as presented in Table 12 above, the calculated figures for SCS, FAA and time lag equations were used to calculate the n values for the various types and condition of soils using the developed model of:

$$T_c = 0.935L^{0.878} n^{0.324} \theta^{-0.222} S^{0.049} i^{-0.075} \qquad (10)$$

where L is the length of the watershed, n is the manning coefficient, ? is the antecedent moisture content, S is the slope of watershed and i is the rainfall intensity. Table 14 below presents the n values using various calculated values of time of concentration for the developed mathematical model.

Table 14: n values using calculated values of time of concentration for the developed mathematical model

S/no	Type of soil	Condition of soil	SCS T_c	FAA T_c	Time Lag T_c
		Undisturbed	3.70	8.87	0.37
1	Sandy	Disturbed	3.48	8.73	0.33
		Undisturbed	1.98	8.41	0.03
2	Sandy Loam	Disturbed	2.69	8.26	0.14
		Undisturbed	0.68	7.64	0.00
3	Clay	Disturbed	1.11	8.17	0.00
		Undisturbed	1.03	7.91	0.25
4	Loam	Disturbed	1.42	7.66	0.22
		Undisturbed	1.82	8.09	0.01
5	Sandy Clay	Disturbed	2.70	8.41	0.15

Source: Musa et. al.,, 2013

It was observed from Table 14 that the time lag equation gave a better result of n values for the North Central soils of Nigeria. It was also observed that the best time of concentration was that determined using the time lag equation which initially could be considered as being too short for water to travel from the most remote area of the plot to the of collection bearing in middle that the rainfall simulator provided water in all areas of the plot almost at the same time are at a steady rate of flow.

The n values obtained ranged between 0.00 (for undisturbed sandy loam and disturbed clay soils) and 0.37 for undisturbed sandy soil. When the values of the research work were compared with the figures obtained by Manning, they were very much similar though he did not work on specified soils as presented in this research.

The developed Manning coefficients and relationships for the various types of soils identify in the study area (North Central of Nigeria) can be applied to other soils with similar characteristics in Nigeria. The calculated values of Manning coefficients can be adopted as a design parameter for various types of construction works within the irrigation farm site of the Research area. Finally, it has been shown that this model provides improved understanding of the hydrologic and hydraulic processes that are most important to the local farmers and structural engineers in Nigeria.(Published in The Electronic Journal of Geotechnical Engineering (EJGE). Vol. 17 (2012, Bund. V.)

2.2.4. Water Harvesting

2.2.4.1. Farming System Assessment of Water Harvesting in Western Africa: The Case of Nigeria.

The study focuses on Water Harvesting (WH) in relation to economic productivity and viability, system fit and acceptability both modern and indigenous. The study was carried out in two contrasting agro-ecological zones, notably the sahel and the sudan savanna.

The two agro-ecological sites have a lot of potentials for WH although its degree of exploitation for farming is currently very low. This study focuses on masakwa farming and the small-basinirrigation, pumping water from ponds using a 2-3” water hose and petrol engine (2 to 3 horse power). Several ponds exist along the natural depressions or excavation pits, about 60% of which were found dry during the field work, 30% served as watering points for livestock, while only 10% are used for farming, fishing and domestic consumption. Water harvesting techniques have not been widely accepted as part of traditional farming system.

The three basic resources required for farming in this region are labour, land and capital. Thebasic source of labour supply is the household which accounts for 70% of the labourrequirements. Variations in farm holding is dictated by the household size on the one hand and occupational diversification and wealth on the other. Other sources of labour include hiredlabour and cooperative workforce. Presently, farmers in this region tend to have restrictedaccess to credit facilities either in cash or kind hence low productivity. Access to land is governed by the land tenure systems. With 70-80% of rural land being communally owned, the Land Use Decree (LUD) notwithstanding.

Constraints to agricultural development are environmental, water and policy: (Socio-economic) and technical constraints. There is poor rainfall and soil conditions as well as tough incidence of pests and plants diseases. Water resources are not only limited but also variable in supply. Further to this, the situation has worsened and aggravated by lack of coherent stable and sustainable agricultural development policy which has resulted into chaotic extension and input delivery systems.
The researcher established the water harvesting availability and its potential in the semi-arid region of Nigeria. By the method of storage-depth curves of the reservoir and water balance analysis, investigations revealed that amount of water ranging between 3,500m^3 and 8,500m^3 was stored in different locations where this study was conducted (Sahel/Sudan Savanna). It was concluded from this study that seepage rate for both site ranges from 0.9 to 19m^3/day while the evaporation rate ranges from 9 to 31m^3/day.

It was recommended that government should assist the local/rural farmer in this region (semi-arid) of Nigeria, in order to make the water harvesting techniques popular. The Ministries of Agriculture and Natural Resources and Rural Development should promote the use of water harvesting techniques by encouraging the building of earth dams, bunds, ridges of about 0.70cm in height with 0.65cm in width and provision of supportive services such as irrigation pumps, extension services and farm inputs. Finally, there is an urgent need for a more detailed study to other geo-ecological zones of Nigeria.
The report was commissioned by the United Nations for Food and Agriculture Organization (UNFAO). The study Team comprised of two National Consultants: a socio-economist as the Team Leader and an Agricultural Engineer. This report was submitted to FAO and forms a

chapter in the book published by Reiji C, Scoones, I and Toulmin C. (eds). titled "SUSTAINING THE SOIL – Indigenous Soil and Water Conservation in Africa", Earthscan Publications Ltd.

Plate

Plate

Plate

Plates1, 2, 3 : Water Harvesting captured in a natural depression in the field
Source: Adewumi and Kolawole 1993

2.2.4.2. Water Harvesting Techniques: Influence of Water Harvesting Practices on Farmer's Productivity in Semi-Arid Areas of Nigeria

Rain water harvesting practices and their effects on the productivity of farming systems in the semi-arid areas of Nigeria have been investigated using participatory rural appraisal (PRA) technique. There was no direct water harvesting interventions by government agencies in the area. Farmers take advantage of naturally existing depressions and abandoned burrow pits close to their farmlands to harvest rain water for surface irrigation using petrol engine pumps. The reservoirs surveyed were found to be grossly inadequate in the drought period. Water budget analysis revealed that evaporation and seepage losses from reservoirs were high in both agro-ecological zone considered. The application of rain water harvesting practices was found to have increased farmers income by 61% and 125% in the Sahel and Sudan Savannah agro-ecological zones, respectively.

The Natural Resources Council of Nigeria (NARESCON) describes drought-prone areas in Nigeria as those lying above latitude 11° North in the country The area comprises of the Sudan Savannah and the Sahel Savannah agro-ecological zones of Nigeria.

The changing trend of global water harvesting reservoirs in the study sites were surveyed for capacity (available water (AW)) and catchment area. Water balance analysis of the water harvesting reservoirs was also carried out to evaluate their adequacy for the drought period using the water budget (WB) model stated. The water demand (WD) considered in the analysis include: livestock use, evaporation, seepage, irrigation and domestic water use where applicable. Potential evaporation (ETo) at the reservoir sites was estimated using Blaney-Criddle model stated.Infiltration rate at the reservoir floor was determined using a double ring infiltrometer and used to estimate seepage rate (SR); livestock use (LWR) was based on estimate of livestock population and daily water requirement for each livestock; irrigation needs (IWR) was estimated using FAO daily water requirement of crops planted at the sites; domestic water use (DWR) was estimated using population figures of the villages where applicable:

$WB = AW - WD = AW - (ETo + IWR + LWR + SR + DWR)$ (1) Positive values of WB shows water surplus, while negative values shows water

deficit: ETo = P(0.46T + 8.13).
where, P is the mean daily percentage of annual daytime hours (%), T is the mean air temperature (°C). Farming system productivity was determined using farm budget analysis of the data collected from randomly selected farmers, the model used is stated in Eq. (3):
NFI = TR – (TVC + TFC) (3) where, NFI = net farm income in Naira (N); TR = total revenue in Naira (N); TVC = total variable cost in Naira (N); TFC = total fixed cost in Naira (N). The farming systems considered include: rain-fed farming (FS I), farming with water harvesting (FS II) and irrigation farming (FS III).

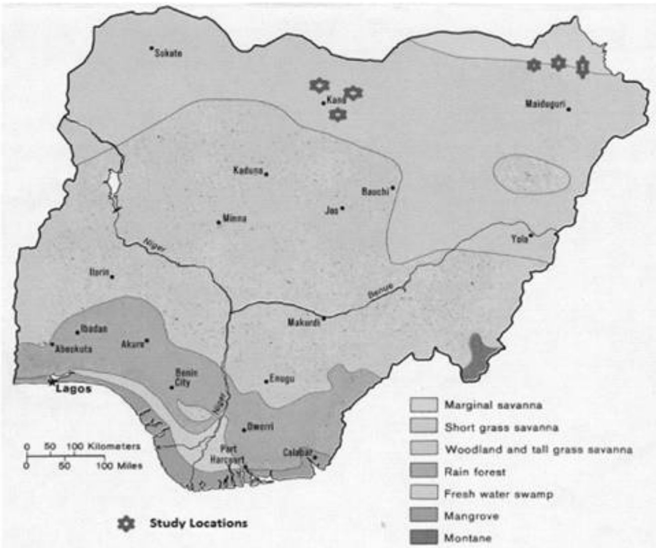


Figure 13 : Agro-ecological zones in Nigeria
Source: Adewumi, et. al., 2011

Table 11: Location of Study Sites

Agro-ecological zone	Village (Local government area, state)	Location	Climate
Sahel Savannah	Kaje (Marte, Borno) Kolbe (Dikwa, Borno) Mafa (Mafa, Borno)	Latitude 12°20'N, longitude 14°11'E Latitude 11°58'N, longitude 13°50'E Latitude 11°53'N, longitude 13°45'E	Rainfall: 250-500 mm Tempeture: 24-27 °C
Sudan Savannah	Tarau (Bebeji, Kano) Wangara (Tofa, Kano) Kafur (Kafur, Katsina)	Latitude 11°42'N, longitude 08°40'E Latitude 11°55'N, longitude 08°20'E Latitude 11°40'N, longitude 07°40'E	Rainfall: 800-1,000 mm Tempeture: 29-35 °C

Source: Adewumi, et.al., 2011

Table 12: Identified farming systems in the Sudan Savannah

Farming system	Local name	Crops cultivated	Cropping season
FS I	*tudu*	Crops are grown in combination: sorghum/groundnut, maize/cotton, millet/sorghum/cowpea, sorghum/maize, cotton/cowpea, millet/groundnut	June-October
FS II	*fadama*	Tomatoes, pepper, onions, rice, carrot, lettuce, cabbage, garden egg, sugar cane, wheat, maize, okro	January-December
FS III	*noman ruwa*	Rice, wheat, tomatoes, pepper, onions	November-April

Source: Adewumi, et. al., 2011

Table 13: Identified farming systems in the Sahel Savannah

Farming system	Local name	Cultivated crops	Cropping season
FS I	*kati kassa*	Maize, sorghum, groundnut and cowpea	July-September
	kati kulum	Maize, cowpea, sorghum and rice	July-September
	kati kulum	Cassava, cowpea, wheat, sorghum, maize, millet, tomatoes, garlic, sweet potatoes, pepper, vegetables, sugarcane	July-September
	firki	Maskwa sorghum	August-January
FS II	*fadama* or *firki*	Water melon, cassava, cowpea, wheat, sorghum, maize, millet, tomatoes, garlic, sweet potatoes, pepper, vegetables, sugarcane	January-December
		Garden egg, cassava, cowpea, wheat, sorghum, maize, millet, tomatoes, garlic, sweet potatoes, pepper, vegetables, sugarcane	July-November
FS III	South Chad irrigation project	Rice and wheat	December-June

Source: Adewumi, et. al., 2011

Table 14: Water balance of identified water harvesting reservoirs in the study area

Agro-ecological zone	Village	Livestock use (m^3/day)	Evaporation (m^3/day)	Seepage (m^3/day)	Irrigation (m^3/day)	Domestic water use (m^3/day)	Total daily water requirement (m^3/day)	Seasonal water requirement (seven months) (m^3)	Available water (m^3)	Water balance (m^3)
		1	2	3	4	5	6 = 1 + 2 + 3 + 4 − 5	7	8	9 = 7 − 8
Sudan Savannah	Tarau	17 (15.5%)	9 (8%)	0.9 (0.8%)	83 (76%)	-	109.9	23,079	3,500	-19,579
	Wangara	17 (44%)	15 (38%)	3 (8%)	-	4 (10%)	39	8,190	8,000	-190
	Kafur	17 (40%)	12 (28%)	1.4 (4%)	12 (28%)	-	42.4	8,904	4,500	-4,404
Sahel Savannah	Kaje	10 (18%)	28 (49%)	19 (33%)	-	-	57	11,970	8,500	-3,470
	Kolbe	10 (27%)	14 (37%)	7 (18%)	7 (18%)	-	38	7,980	4,200	-3,780
	Mafa	10 (14%)	31 (42%)	19 (26%)	3 (4%)	10 (14%)	73	15,330	8,900	-6,430

Source: Adewumi, et. al., (2011)

Plate 4

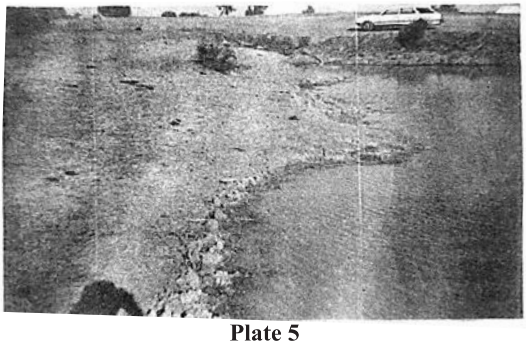


Plate 5

Plate 6

Plates4, 5, 6: Water harvested in a natural depression in the field
Source: Adewumi et. al., 2011

The water harvesting based also proved to be dependent on low external inputs in the Sahel zone; labour and seed procurement accounted for 70% and 30% of the total variable costs, respectively. The average net household income of farmers practicing this system was N4,661/ha. It is important to note that this system is only complimentary to the other farming systems and has resulted to increased income for the farmers; by this, farmers are able to engage the land for additional 3-4 months in the year. This indigenous farming system has fulfilled the need established by the FAO (2002) for obtaining more crop yield for every drop of water used.

The study revealed a number of indigenous techniques used for soil moisture conservation. There was no evidence of direct intervention by the government for the construction of water harvesting structures. Available structures only exist by chance and few farmers take advantage of them.

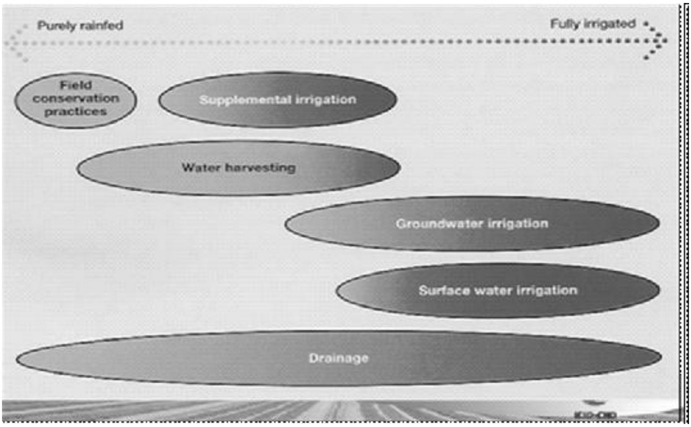


Plate 7: Summary of water harvesting techniques for Crop Production in Nigeria.

2.2.4.3. Evaluation of the Penman–Monteith reference evapotranspiration under limited data and its sensitivity to keyclimatic variables under humid and semiarid conditions

The objectives of this study were to assess the accuracy of FAO Penman Monteith equation (FAO PM) under limited data conditions and to perform sensitivity analysis to determine approximately the change in reference evapotranspiration (ETref) expected for a known change in one of the independent variables and derive the sensitivity coefficient. Meteorological data were collected from 8 weather stations under humid and semiarid conditions in Côte d'Ivoire. The results showed good performance of FAO PM equation under missing solar radiation (Rs) in semiarid condition and under missing wind speed data (U_2) and relative humidity (RH) in all locations with coefficient of determination (R_2) ranging from 0.70 to 0.99 and regression slope from 0.99 to 1.05. Under missing Rs, RMSE varied from 0.45 to 0.48 mm/day and AME from 0.30 to 0.35 mm/day. The RMSE and AME vary respectively from 0.12 to 0.51 mm/day and from 0.09 to 0.30 mm/day under missing RH data, and respectively from 0.11 to 0.60 mm/day and 0.04 to 0.34 mm/day under missing wind speed data. The poor performance of FAO PM method to estimate ETo was observed when three climatic variables were missing with regression slope from 0.93 to 1.06 and R_2 from - 0.06 to 0.26. The response of ETo to changes in all climate variables was linear, with high R_2 values ($\geq$0.99) in most cases. Any error in Rs, maximum temperature (Tmax) data would have contributed to significant change in ETo estimate. The effect of Rs on change in ETo estimates had the greatest slope ($\geq$2.80) in Bouake, Daloa, Korhogo, Man, Seguela whereas it had the lowest slope in Ferkessedougou (slope = 2.74), Odienne (slope = 2.73), Yamoussoukro (slope = 2.77). The effect of Tmax in change in ETo was also important in all locations except Daloa and Man with low regression slope values of 1.63, 1.74, respectively. All sensitivity coefficients showed a large degree of daily and seasonal fluctuations and revealed significant differences in northern and central study locations. The sensitivity coefficients of U_2 and Tmax were greatest under semiarid condition while the one of Rs were very high in humid condition. Accurate measuring of U_2, Tmax and Rs in estimating reference evapotranspiration using Penman–Monteith equation is required.

2.2.4.4. Study area and meteorological data used

This study covers different climatic zones ranging from humid in the middle to semiarid in the north of Côte d'Ivoire. Meteorological data were collected from 8 weather stations. Korhogo, Odienne and Ferkessedougou study sites are located in the northern part of the country under semiarid climate while Seguela, Bouake, Man, Daloa, Yamoussoukro are located in the central part of the country under tropical humid climate.

Accuracy of Penman–Monteith equation was assessed under limited data conditions and the sensitivity analysis of the Penman–Monteith equation to climatic variables such as wind speed at 2 m (U_2), maximum air temperature (Tmax), minimum air temperature (Tmin), maximum relative humidity (RHmax), minimum relative humidity (RHmin), and solar radiation (Rs) was conducted for the humid and semiarid conditions in Côte d'Ivoire.

The results showed that under missing solar radiation, the procedures proposed for estimating solar radiation from maximum and minimum daily air temperatures yielded good results in semiarid condition. In all locations, good performance was obtained under missing daily average wind speed. Good performance was also obtained when minimum temperature was used to estimate the actual vapor pressure under lacking relative humidity data.

The poor performance of FAO-PM method to estimate ETo was observed when three climatic variables were missing. The response of ETo to changes in all climate variables was linear, with high R_2 values ($\geq$ 0.99) in most cases. Among the climatic variables, ETo was more sensitive to Rs and Tmax in all locations followed by Tmin at Bouake, Seguela and Yamoussoukro and U_2 at other study sites. The sensitivity coefficients of U_2 and Tmax were high under semiarid condition while the ones of Rs were high in humid condition. Daily sensitivity coefficients showed considerable fluctuations over the seasons, and the magnitude of ETo to the same variable varied considerably amongst the locations.

The sensitivity analyses and sensitivity coefficients of this study can be useful to assess the importance and role of each climate variable in estimating ETo using the daily form of Penman–Monteith equation. Our findings revealed that emphasis should be given when measuring U_2, Tmax and Rs in estimating reference evapotranspiration using Penman–Monteith equation. It is important that other simple ETo equation should be evaluated, calibrated, and validated when more than one climatic variable is missing under West Africa humid and semiarid climatic conditions.

2.3. Irrigation and Food Security

2.3.1. Computer Aided Drip Irrigation Design for Nigerian Agricultural Environment.

Plates 8, 9, 10: Various Irrigation method in use.

Plate 8

Plate 9

Plate 10: Furrow irrigation

Plate 11: Surface irrigation using syphon tube

It was discover that drip irrigation is the most appropriate option. But drip irrigation system requires a carefully design procedure that is highly sensitive to crop type, location and soil condition. A***computer-based*** software package was developed for designing drip irrigation system which employs appropriate design parameters such as; soil type, crop factor, hydraulic and hydrology factors, Evapotranspiration (ET), Relative Humidity (RH) and field topography. The software package was developed using PHP programming language, Dreamweaver and MySQL Database. It comprised of a number of user's interfaces that provide drop-down option menu lists containing design elements from amongst which users could freely select. The output template (which defines a typical irrigation field layout) contained such parameters as: Field length, field breadth, crop inter- and intra-row spacing, plant population, per plant water application, field water application, irrigation return period and pump capacity. The package requires 32 Gb memory space and a processing speed of 270 KHz to run on a Pentium IV Computer system commonly available in the Nigerian market. They usedthe output template to set up a 0.4Ha irrigation fieldand planted with pepper and okra during the dry months of 2011, 2012 and 2013 to validate the performance of the developed software package. Irrigation water requirement of 1.0 liter/day was used as a standard. The field results obtained showed that there was an optimal crop performance of both okra and pepper. This result agreed with Food and Agric Organization irrigation practice standard. In the study, a software was developed that was able to predict optimal parameters required for an efficient drip irrigation system and this could be used as a baseline for a national automated irrigation system.

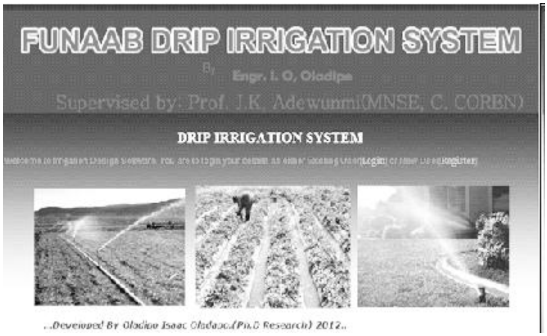


Plate 12: Design of Computer Aided Drip Irrigation for FUNAAB Soil
Source: Oladipo and Adewumi (2013)

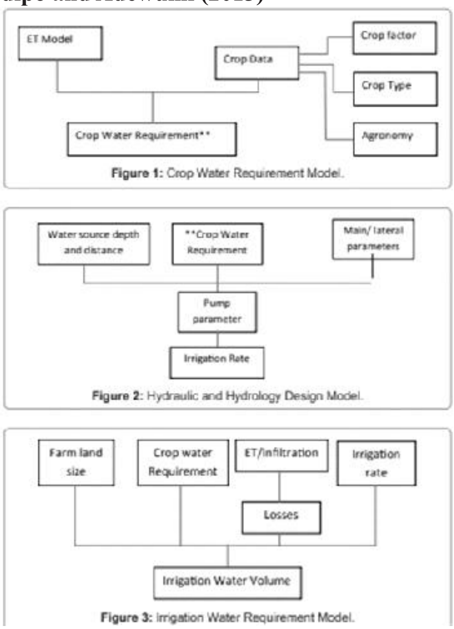


Figure 14 : Organogram for the computer Aided Design of Drip Irrigation
Source: Oladipo and Adewumi (2013)

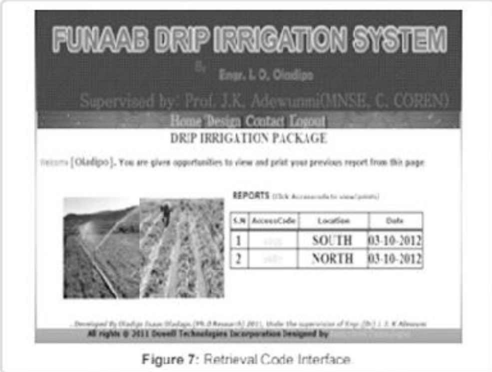


Figure 7: Retrieval Code Interface.

Figure 15 : Output Design result of Drip Irrigation for FUNAAB Soil Source: Oladipo and Adewumi (2013)

Figure 5: Front window interface.

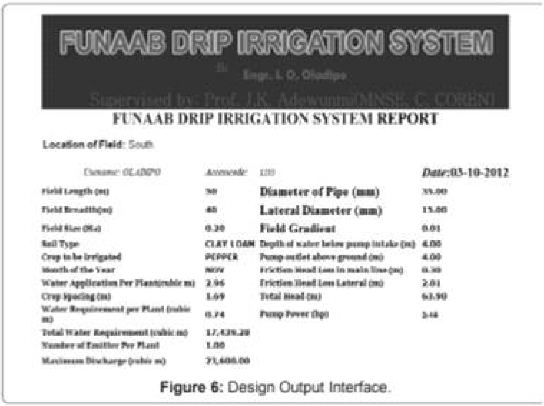


Figure 6: Design Output Interface.

Figure 16 : Output Design result of Drip Irrigation for FUNAAB Soil Source: Oladipo and Adewumi (2013)

2.3.2. Climate Change

2.3.2.1. Impact of Climate Variability on Crop Yields in Southern Togo

The objectives of this study were to investigate the trend in monthly and annual precipitation, minimum and maximum air temperature using the Mann-Kendall test and Sen's slope estimator and to evaluate the impact of precipitation and temperature variability on crop yields in southern Togo using multiple regression analysis. Monthly precipitation and temperature for four weather stations were collected from 1970 to 2014. A non-significant increasing trend in annual precipitation (P>0.05) was noticed in Atakpamé, Lomé and Tabligbo, while Kouma-konda revealed a non-significant decreasing trend (P>0.05). During the growing season, July had the highest precipitation (208.7 mm) in Atakpamé, June had the highest precipitation in Lome (198.5 mm) and Tabligbo (158.7 mm). Amongst the locations, Kouma-konda has the highest monthly precipitation (226.2 mm) obtained in June. There was a significant increasing trend (P<0.0001) in Tmin and Tmax at all locations except in Kouma-konda where Tmax has decreased insignificantly. In Atakpame and Tabligbo, the precipitation and temperature have non-significant effect on the crop yields with very low coefficient of determination ranging from 0.024 to 0.107. In Kouma-konda, the increase of temperature has a significant effect on maize and beans. Therefore, climate projection studies and adaptation strategies for agriculture are recommended for yield stability in locations where crops are affected by climatic variability.

Site description and data collection

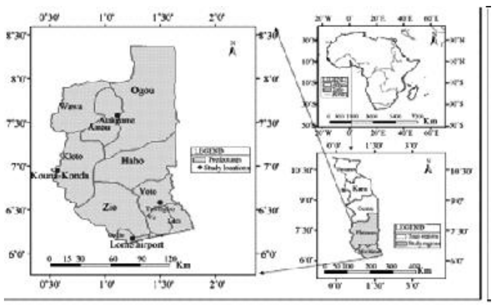


Figure 17: Map of southern Togo indicating the weather stations
Koudale et. al., 2018

Togo is a small West African nation with estimated population of about 6,191,155 inhabitants [26]. It borders in the south by Atlantic Ocean; Ghana lies to the west; Benin to the east; and the north of Togo is bound by Burkina Faso. Togo lies mostly between Latitudes 6° and 11°N and Longitudes 0° and 2°E.

Table 15: Coordinates, mean annual values and standard deviations of climate variables under study at the meteorological stations

	Characteristics	Atakpamé	Kouma-konda	Lomé	Tabligbo
	Latitude	7°31'37"N	6°95'N	6°9'56"N	6°34'59"N
Coordinates	Longitude	1°7'36"E	0°58'E	1o15'16.24"E	1°30'00"E
	Elevation (m)	250	643	22	76
	Precipitation (mm)	1397 ± 413	1597 ± 386	829 ± 220	902 ± 365
Climate variables:	T_{min} (°C)	21.5 ± 0.44	20.0 ± 0.57	23.9 ± 0.77	22.6 ± 0.51
long-term average	T_{max} (°C)	31.5 ± 0.55	28.9 ± 0.52	31.3 ± 0.61	32.9 ± 0.57
	T_{mean} (°C)	26.5 ± 0.48	24.4 ± 0.32	27.6 ± 0.64	27.8 ± 0.49

Source: Koudale et. al., 2018

$$S=\sum_{j=1}^{n-1}\sum_{i=j+1}^{n} sign(x_i-x_j) \quad (1) \qquad (11)$$

where xi is the data value at time i, n is the length of the dataset and gn (x_i-x_j) is the sign function which can be computed as:

$$sign(x_i-x_j)=\begin{cases} 1 \ if\ (x_i-x_j)>0 \\ 0 \ if\ (x_i-x_j)=0 \\ -1\ if\ (x_i-x_j)<0 \end{cases} \quad (2) \qquad (12)$$

For n>10, the test statistic Z approximately follows a standard ormal distribution:

$$Z=\begin{cases} \frac{S-1}{\sqrt{Var(s)}} \ if\ S>0 \\ 0 \quad if\ S=0 \\ \frac{S+1}{\sqrt{Var(s)}} \ f\ S<0 \end{cases} \quad (3) \qquad (13)$$

in which Var(S) is the variance of statistic S.

$$S=\sum_{f=1}^{n=1}\sum_{i=f+1}^{n} sign(\chi_i - \chi_j) \qquad (14)$$

Koudale et.al., 2018

A positive value of Z indicates that there is an increasing trend, and a negative value indicates a decreasing trend. The null hypothesis, Ho, that there is no trend in the records is either accepted or rejected depending on whether the computed Z statistics is less than or more than the critical value of Z statistics obtained from the normal distribution table. The Theil-Sen estimator (TSE) is an unbiased estimator of the true slope in simple linear regression If there is a trend in the data, the magnitude of the change in any variable can be denoted by trend slope ß

$$\beta = Median\left(\frac{x_i - x_j}{i - j}\right)$$

$$\forall_j < I \qquad (4)$$

where x_i and x_j are data values at time t_i and t_j ($i > j$), respectively.

2.3.2.2 Impact of variation in climatic variables on crop yields.

The precipitation and temperature data were tested against crop yields in southern part of Togo. Yield records of 5 major crops commonly grown in southern of Togo was collected at the Ministry of agriculture, livestock and hydraulic from 1990 to 2014. Lome is not an agriculture production area so; no yield record has been obtained. The crops for which data are available are maize, rice, cassava, cowpea and groundnut. Amongst these crops, only rice is irrigated in southern Togo. Multiple regression analysis was carried out on the crop yield using growing season precipitation and temperature values covering 1990 to 2014 period. The Statistical analysis software STATA was used to perform the Student t-test. This had enabled the possible determination of relationships between the precipitation, temperature and crop yield in southern of Togo. When the probability associated with t-student is less than 5%, then the independent variable has a significant influence or contributes to the variation in crop yield. The equation associated with the change in yield as a function of precipitation and temperature is:

$$\gamma = C + aT + bT + \epsilon \qquad (15)$$

Where γ is the yield (kg), a temperature-related coefficient, T temperature data (°C), b precipitation coefficient, P the precipitation data (mm) and ε error term or other variables which have an influence on the yields, C the constant.

Table 16: Summary of the Mann-Kendall trend test in annual precipitation and annual minimum and maximum monthly temperature

Locations	First year	Last year	n	Mean	Test Z	Significance	Sen's slope estimate
Precipitation (mm)							
Atakpame	1970	2014	45	1397	0.6	n.s.	2.17
Kouma-konda	1970	2014	45	1597	-0.34	n.s.	-1.3
Lomé	1970	2014	45	829	0.95	n.s.	2.33
Tabligbo	1971	2014	44	902	1.1	n.s.	2.26
Maximum temperature (°C)							
Atakpamé	1971	2014	44	31.5	6.04	***	0.034
Kouma-konda	1971	2014	44	28.9	-0.46	n.s.	-0.003
Lomé	1971	2014	44	31.3	5.99	***	0.04
Tabligbo	1971	2014	44	32.9	6.18	***	0.036
Minimum temperature (°C)							
Atakpamé	1971	2014	44	21.6	6.39	***	0.027
Kouma-konda	1971	2014	44	20	5.42	***	0.035
Lomé	1971	2014	44	23.9	6.26	***	0.048
Tabligbo	1971	2014	44	22.6	5.17	***	0.029

n.s.: Non-Significant
***Significant 0.1%

Source: Koudale et. al., 2018

Table 17: Summary of the trends analysis in monthly precipitation during growing season in Atakpame, Kouma-konda, Lome and Tabligbo

	Atakpamé			Kouma-konda			Lomé			Tabligbo		
Months	Mean	Sen's slope	Significance	Mean	Sen's slope	Significance	Mean	Sen's slope	Significance	Mean	Sen's slope	Significance
Precipitation												
January	6.6	0.00	n.s	23.5	0.00	n.s	11.4	0.00	n.s	7.6	0.00	n.s
February	23.6	-0.07	n.s	52.5	0.47	n.s	21.9	0.00	n.s	31.0	-0.34	n.s
March	76.1	-1.64	*	117.9	-1.74	*	55.7	0.13	n.s	96.1	-0.05	n.s
April	125.2	0.17	n.s	153.0	-0.63	n.s	94.1	0.20	n.s	117.1	0.17	n.s
May	158.2	0.39	n.s	163.9	0.03	n.s	155.0	0.45	n.s	152.3	0.26	n.s
June	188.3	0.03	n.s	226.2	-0.07	n.s	198.5	-0.14	n.s	158.7	0.70	n.s
July	208.7	1.02	n.s	197.1	-0.64	n.s	76.5	0.50	n.s	89.6	0.77	n.s
August	196.1	0.56	n.s	154.0	-1.13	n.s	32.3	0.43	+	55.5	0.47	n.s
September	204.1	0.63	n.s	238.5	-0.01	n.s	69.1	0.49	n.s	121.2	-0.10	n.s
October	124.2	0.56	n.s	192.4	0.41	n.s	87.9	1.19	+	130.6	0.81	n.s
November	14.5	-0.01	n.s	70.9	0.52	n.s	18.5	0.05	n.s	41.4	0.64	+
December	13.2	0.00	n.s	30.5	0.00	n.s	7.8	0.00	*	14.7	0.00	n.s

n.s.: Non-Significant
+ Significant at 10%
* Significant at 5%

Source: Koudale et. al., 2018

2.3.2.3 Trend analysis

For the analysis of trend in annual and monthly maximum and minimum air temperature and annual and monthly precipitation, the Mann-Kendall test, a nonparametric method for trend analysis, was used.

2.3.2.3.1. Impact of variation in climatic variables on crop yield

The results of multiple regressions of precipitation and temperature on crop yields are presented below. In Atakpame, the results revealed that the precipitation and temperature have non-significant effect on the yields record. In Kouma-konda, the results revealed that the temperature has significant influence on the variation of maize yields ($p<0.1$) and on cowpea ($p<0.01$). For other selected crops in Kouma-konda, it is shown that the variation of precipitation and temperature have nonsignificant effect on them. In Tabligbo, for all the selected crops, the variation of precipitation and temperature have non-significant effect on the crop yields.

In Kouma-konda, Tmin rose by 0.4°C and Tmax decreased by 0.3 per decade. Tmin is found to increase faster than Tmax. The coastal area (Lomé) has the highest increase in annual and monthly Tmin and Tmax. Results of multiple regression analysis revealed that in Atakpame and Tabligbo, neither the precipitation nor the temperature have effect on the selected crop yields. In Kouma-konda, it revealed that the increased of temperature has significant effect on maize and bean. The increasing trend in Tmin and Tmax implies an increase in evapotranspiration which is of great concern to crop producers. Therefore, specific actions such as water management practices, crop diversification, new drought-resistant seed etc. are needed for resource planning and management for the sustainability of agriculture for future generations.

2.3.2.3.2.Trend Analysis in Standardized Precipitation Index and Standardized Anomaly Indexin the Context of Climate Change in Southern Togo.

Rainfall and temperature are climatic variables mostly affected by global warming. This study aimed to investigate the temporal trend analysis in annual temperature and rainfall in the Southern Togo for the 1970-2014 period. Daily and annual rainfall and temperature were collected from four weather stations at Atakpame, Kouma-Konda, Lome, and Tabligbo. The temperature variability was determined by the Standardized Anomaly Index (SAI) and the annual rainfall variability was determined using the Standardized Precipitation Index (SPI). The Mann-Kendall test was used for trend analysis. Mann-Kendall statistical test for the mean annual, mean annual minimum and maximum temperature from 1970 to 2014 showed significant warming trends for all stations.

The Mann-Kendall test revealed an increasing trend in standardized anomaly index at all the sites, prejudicial to rainfed agriculture practiced by about 90% of Togolese crop growers. The trend analysis in the climate variables indicated a change in climate that necessitates some specific actions for resources management sustainability and conservation.

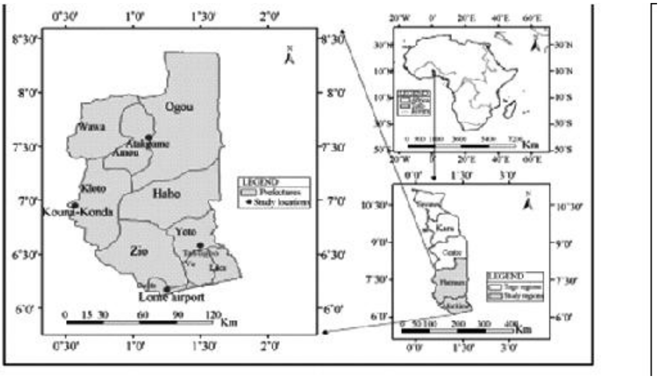


Figure 18: Map of southern Togo indicating the weather stations Koudale et. al., 2018

2.3.2.3.3. Standardized Anomaly Index Estimation Model (SAI)

For each of the stations, annual mean temperature, mean annual minimum temperature and mean annual maximum temperature series were analyzed for fluctuation using Standardized Anomaly Index (SAI) which is a commonly used index for regional climate change studies. Station temperature is expressed as a standardized departure i x from the long-term mean (i.e. the mean of the base period), calculated as:

$$x_i = \frac{r - r_i}{\sigma} \qquad (16)$$

where r is the mean temperature of the year, ri is the long-term mean, and σ is the standard deviation of annual mean temperature for the long-term. A period when below long-term average was dominated is considered as cooling period and a period when above long-term average was most persistent is a warming period.

2.3.2.3.4. Standardized Precipitation Index Estimation Model (SPI)
The concept was developed by for the purpose of defining and monitoring drought. In order to calculate SPI values, historical monthly rainfall were fitted to gamma distribution whose probability density function is defined as:

$$g(x) = \frac{1}{\beta^{\alpha}\tau(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}} \quad \text{for } x > 0 \qquad (2) \qquad (17)$$

where $g(x)$ is probability density function, α is a shape parameter ($\alpha > 0$), β is a scale parameter ($\beta > 0$), ($x > 0$) and

$$\tau(\alpha) = \int_0^{\alpha} y^{\alpha-1} e^{-1} dy \qquad (3) \qquad (18)$$

where $\tau(\alpha)$ is the gamma function.

The parameters α and β are estimated using the following formulae

$$\alpha = \frac{1}{4A}\left[1 + \sqrt{1 + \frac{4A}{3}}\right] \qquad (4) \qquad (19)$$

$$\beta = \frac{\bar{x}}{\alpha}$$

where $A = \ln \bar{x} - \frac{\sum \ln \bar{x}}{n}$ and n being the number of precipitation observations, and $\bar{x}$ is the mean precipitation over the time scale of interest.

When the probability density function is integrated with respect to x using the estimates of α and β, a cumulative probability G x( ) of an observed amount of rainfall in a given month and time scale is obtained as follows:

$$G(x) = \int_0^x g(x)\,dx = \frac{1}{\bar{\beta}^{\bar{\alpha}}\tau(\bar{\alpha})}\int_0^x x^{\bar{\alpha}} e^{\frac{\bar{x}}{\beta}}\,dx \qquad (20)$$

Substituting t for $\frac{\bar{x}}{\bar{\beta}}$ in the equation above gives

$$G(x) = \frac{1}{\tau(\bar{\alpha})}\int_0^x t^{\bar{\alpha}-1} e^{-t}\,dt \qquad (21)$$

which is the incomplete gamma function. However, the gamma distribution function is undefined for x = 0 and q Px = = >(0 0) where P x(= 0) is the probability of zero precipitation. Therefore, the actual probability of non-exceedance H x(0) should be calculated as follows:

$$H(x) = q + (1-q)G(x) \qquad (22)$$

where H x( ) is actual probability of non-exceedance and q the probability of x = 0 . If m is the number of zero in a sample of size n, then q is estimated as:

$$q = \frac{m}{n}. \qquad (23)$$

Finally, the cumulative probability distribution H x( ) , is transformed into the standard normal distribution to yield the SPI. However, due to the complexity of following these steps to compute SPI manually, the United States National Drought Mitigation Centre developed a program that computes SPI from monthly precipitation data at required time scales. This SPI program (SPI_SL_6.exe) available at: (http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx) was downloaded and used in this research. All negative SPI values indicate the occurrence of drought, while all positive values stand for wet periods. A table of SPI magnitude as presented in Table 22 was used to determine wet or dry intensity over the study area of Togo.

Table 18: SPI values and interpretation

SPI value	Interpretation
≥2.0	Extremely wet
1.5 to 1.99	Severely wet
1.0 to 1.49	Moderately wet
0.99 to −0.99	Near normal
−1.0 to −1.49	Moderately dry
−1.5 to −1.99	Severely dry
≤−2.0	Extremely dry

Source: Koudale et. al., 2018

Various time scales are used for the computation of SPI on which changes in precipitation can affect different aspects of hydrologic cycle. These time scales include 1, 3, 6, 9, 12, 24, 36 months. The choice of these time scales depends on the interest of research. In this study, the time series of SPI 12 month time scale was utilized to compute SPI for the precipitation data from 1970 to 2014 to determine the frequency of occurrence of wet/dry conditions and the risk of flood and drought in southern part of Togo.

2.3.2.3.5. Temporal Trend Analysis

For the analysis of temporal trend in standardized anomaly index and standardized precipitation index, the Mann-Kendall test [38] [39] [40], a nonparametric method for trend analysis, was used. It should be noted that the Mann-Kendall test statistic is non-dimensional, and it does not offer any quantification of the scale of the trend in the units of the time series under study, but is rather a measure of the correlation of a variable with time and, as such, simply offers information as to the direction and a measure of the significance of observed trends. The Mann-Kendall test statistic S is given as follows:

$$S = \sum_{j=1}^{n-1} \sum_{i=j+1}^{n} \operatorname{sign}(x_i - x_j) \tag{24}$$

where xi is the data value at time i, n is the length of the dataset and sign( ) is the sign function which can be computed as:

$$\operatorname{sign}(x_i - x_j) = \begin{cases} 1 & \text{if } (x_i - x_j) > 0 \\ 0 & \text{if } (x_i - x_j) = 0 \\ -1 & \text{if } (x_i - x_j) < 0 \end{cases} \tag{25}$$

For n > 10, the test statistic Z approximately follows a standard normal distribution

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases} \tag{26}$$

in which Var(S) is the variance of statistic S.
A positive value of Z indicates that there is an increasing trend, and a negative value indicates a decreasing trend. The null hypothesis, Ho, that there is no trend in the records is either accepted or rejected depending on whether the computed Z statistics is less than or more than the critical value of Z statistics obtained from the normal distribution table at the 5% significance level [41].

If, $|Z| > Z_{(1-\alpha/2)}$, the null hypothesis of no autocorrelation and trend in dataset is rejected, in which $Z_{(1-\alpha/2)}$ is corresponding to the normal distribution with α being the significance level. If the data has a trend, the magnitude of trend can be denoted by trend slope β

$$\beta = \text{Median}\left(\frac{x_i - x_j}{i-j}\right), \ \forall j < i \qquad (27)$$

where xi and xj are data values at time ti and tj(i > j), respectively.

Table 19: Probability of occurrence 12-month SPI at Lome

SPI	Category	Number of time in 45 years	Percentage of occurrence	Severity of events
≥2	Extremely wet	3	1.8%	1 in 15 years
1.5 - 1.99	Severely wet	9	5.4%	1 in 5 years
1 - 1.49	Moderately wet	22	13.2%	1 in 2.1 years
0 - 0.99	Mild wetness	51	30.5%	1 in 0.88 year
0 to −0.99	Mild dryness	42	25.2%	1 in 1.1 years
−1 to −1.49	Moderately dry	21	12.5%	1 in 2.1 years
−1.5 to −1.99	Severely dry	13	7.8%	1 in 3.5 years
≤−2	Extremely dry	6	3.6%	1 in 7.5 years
Total		**167**	**100%**	

Source: Koudale et. al., 2018

Table 20: Probability of occurrence of 12-month SPI at Tabligbo

SPI	Category	Number of time in 44 years	Percentage of occurrence	Severity of events
≥2	Extremely wet	0	0%	--
1.5 - 1.99	Severely wet	10	5.7%	1 in 4.4 years
1 - 1.49	Moderately wet	30	16.9%	1 in 1.5 years
0 - 0.99	Mild wetness	51	28.8%	1 in 0.86 year
0 to −0.99	Mild dryness	44	24.9%	1 in 1 year
−1 to −1.49	Moderately dry	19	10.7%	1 in 2.3 years
−1.5 to −1.99	Severely dry	13	7.3%	1 in 3.4 years
≤−2	Extremely dry	10	5.7%	1 in 4.4 years
Total		**177**	**100%**	

Source: Koudale et. al., 2018

The trend analysis was performed in Standardized Anomaly Index and Standardized Precipitation Index for southern Togo using the Mann-Kendall test and Sen's slope estimator. Results for standardized anomaly index indicated that there are significant warming trends for the mean annual, mean annual minimum and maximum temperature in the period 1970-2014 for all stations except in Kouma-Konda where mean annual maximum temperature exhibited non-significant cooling trend (P = 0.01). Mean annual temperature, mean annual minimum and maximum temperatures increased respectively from 1.2℃; 1.1℃; 1.3℃ in Atakpamé to 1.9℃; 2.2℃; 1.7℃ in Lomé between 1970 to 2014 but drop slowly to 1.4℃; 1.2℃; 1.7℃ in Tabligbo during the same period.
The information provided by this study can be to support at local level decision-makers in order to monitor flood and drought. Therefore, agricultural planning and government policies in these areas should be based on recent rainfall, temperature trends. This study should be extended to other drought and flood prone area and to all over the country at large and the impact of the climate variability on crop yields should also be investigated. (This paper is published in Atmospheric and Climate Sciences of 2017).

2.3.2.3.6. Drought quantifications in semi-arid regions using precipitation effectiveness variables.

This study proposes a new drought index (DI) based on several precipitation -based parameters to quantify drought hazard in semi arid region. In addition to the practice of using only rainfall volume for indexing drought, the proposed index verifies the potentials of nine (9) other precipitation effectiveness variables (PEVs); namely (onset of rain, cessation of rain, length of rainy and dry season, wet days and dry days within a wet season, dry days within the year, maximum dry spell length within a wet season and mean seasonal rainfall depth (MAR); in quantifying the drought conditions over a place. The Conjunctive Precipitation Effectiveness Index (CPEI), as proposed in this study, utilizes a mathematical model, that algebraically combines "standardized seasonal PEV difference or deficit in each prevailing PEV" and terms of their sequent higher powers to define a single numerical value for this "at-site" drought index approach. Since the results expected from the use of various PEV combinations will defer; it is very necessary that the optimum PEVs combination be pre-determined and later employed for each "at-site" drought evaluation.

By redefining these PEVs , their standardized values is mathematically

$$_{k}SV_{l,j} = \frac{_{k}V_{l,j} - {_{k}\bar{V}_{l,j}}}{\sigma_{_{k}V_{j}}} \qquad (28)$$

where k stands for the PEV variable under consideration (i.e. for ORS, k=1, LRS, k=2, LRS, k=3 …., MDL, k=9 and MAR, k=10). l is the year under consideration, j is the season under consideration (for the monthly step data, j varies from 1 to 12 seasons $_{k}\bar{V}_{l,j}$ and $\sigma_{_{k}V_{j}}$ are respectively the mean and standard deviation for the jth season and for variable k. By using Equation (1) the seasonality inherent in the PEVs can be removed and its values can be compared across various seasons. Conceptually, the standardized difference value $(_{k}SV_{l,j})$ and its higher powers for each PEVs is summed for the most suitable combination of PEVs to calculate CPEI for any year (l) or season (j) under consideration at any particular location. In formulating the model for CPEI in equation below, the value $_{k}SV_{l,j}$ of was intentionally and respectively raised to the power of one, two and three so as to create a "magnifying effect of these standardized differences" in the evaluation of the CPEI index. The sign, k SGN was also included in the CPEI model, so as not to lose the effect of a negative difference (deficit) when it is squared or raised to higher power. Similarly, raising this standardized difference to a power of four or more has been proved to make little difference to the performance of the CPEI model (Otun, 2005).

$$CPEI_{l,j} = \frac{1}{3}\left(\left[\frac{1}{nv}\sum_{m=1}^{nv}\left({}_{k}SV_{l,j}\right) \right] + \left[\frac{1}{nv}\sum_{m=1}^{nv}\left({}_{k}SV_{l,j}\right)^{2} * \left({}_{k}SGN\right) \right] + \left[\frac{1}{nv}\sum_{m=1}^{nv}\left({}_{k}SV_{l,j}\right)^{3} \right] \right) \quad (25)$$

where nv is the no of PEVs in the arrangement, ${}_{k}SV_{l,j}$ is the standardized difference value and k SGN is the sign of the difference for the variable k. By carrying out two comparative tests, the most appropriate PEVs combination for indexing the drought condition of any particular locality can be subjectively determined. The first test referred to as predictive ability comparative test (PACT), uses some statistical procedures to compare the set of CPEI values obtained for various seasons and for each of the possible 1023 arrangements with the corresponding set of values obtained for each other three, four or five meteorological drought indices. This helps to determine the performance of each PEVs in the computation of CPEI and possibly serve as the clue in the preliminary elimination of some PEVs with poor performance.

Table 21: Percentage Distribution of Total PEVs Used to Obtain CPEI with an Average Score (R>0.8) in each Station under Study

	Frequency of Occurrence of total variables Used to Score R > 0.8 (%)							
	NOC[1]	7	6	5	4	3	2	1
Gusau	37	0.0	0.0	13.3	40.0	33.3	6.7	6.7
Kanoap	43	0.0	16.3	30.2	25.6	18.6	7.0	2.3
Katsina	54	1.9	13.0	27.8	22.2	25.9	7.4	1.9
Maiduguri	28	0.0	3.6	14.3	35.7	32.1	10.7	3.6
Nguru	65	4.6	16.9	29.2	24.6	15.4	6.2	3.1
Potiskum	60	3.4	22.0	23.7	25.4	20.3	3.4	1.7
Sokoto	64	4.7	17.2	31.3	25.0	17.2	3.1	1.6

[1]NOC – Total number of occurrence (i.e No of arrangements out of 1023 with average score R> 0.8)

Source: Otun and Adewumi 2009

Table 21 gives the frequency of occurrence of each PEV in the lots of arrangements with average score R>0.8. At 50% level of occurrence, variables no 10 and 4 (i.e MAR and TWD) predominates in all the stations and at 40% level of occurrence, variables 10, 4, 8 and 1 (i.e. MAR, TWD, LDS and ORS) becomes the most predominant variables.

Table 22: Performance Level of Each PEVs (%)

	PEVs (with Corresponding Code and Variable No).									
	MAR	MDL	LDS	TDY	TDW	TDS	TWD	LRS	CRS	ORS
Station	10	9	8	7	6	5	4	3	2	1
Gusau	100.0	13.3	46.7	20.0	20.0	0.0	73.3	40.0	0.0	33.3
Kanoap	100.0	14.0	48.8	20.9	27.9	37.2	79.1	44.2	4.7	46.5
Katsina	100.0	40.7	38.9	25.9	20.4	25.9	75.9	29.6	7.4	48.1
Maiduguri	100.0	21.4	28.6	28.6	3.6	46.4	71.4	14.3	0.0	42.9
Nguru	98.5	9.2	40.0	13.8	18.5	56.9	80.0	27.7	36.9	58.5
Potiskum	100.0	41.7	48.3	18.3	15.0	56.7	81.7	38.3	5.0	46.7
Sokoto	100.0	28.1	50.0	17.2	20.3	54.7	78.1	31.3	12.5	59.4

Source: Otun and Adewumi 2009

Tables 20 and 21 show that the CPEI values obtained by using a combination of three (3), four (4), or five (5) PEVs respectively, has good rankings and highest frequency of occurrence in all the stations under study. The use of these variables has also resulted in high level of performance (average R > 0.9) in most stations under study.

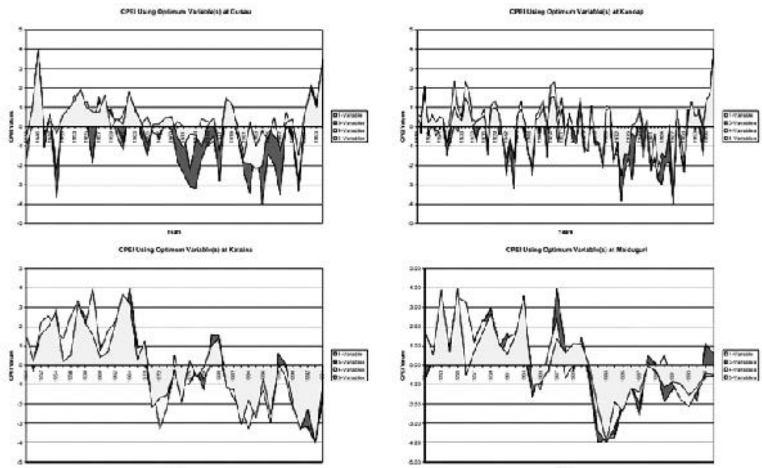


Figure 19 : Comparison of optimum CPEI obtained using 1, 3, 4, and 5 PEVs at four stations under study

Source: Otun and Adewumi 2009

Table 27: Optimum PEV Combinations for Indexing Drought in each Station under Study

Station	Optimum No of PEV	Suggested PEV Combination (Codes)	[1]Combined PEVs	Pearson Correlation Coefficient (R)			
				SPI	RAI	BMDI	Average
Gusau	3	10,7,4	MAR, TDY, TWD	0.960	0.940	0.950	0.950
Kanoap	3	10,7,4	MAR, TDY, TWD	0.956	0.971	0.935	0.954
Katsina	5	10,7,4,3,1	MAR, TDY, TWD, LRS, ORS	0.935	0.943	0.944	0.941
Maiduguri	4	10,9,4,1	MAR, MDL, TWD,ORS	0.881	0.866	0.889	0.879
Nguru	4	10,4,3,1	MAR, TWD,LRS,ORS	0.936	0.929	0.934	0.933
Potiskum	4	10,6,4,1	MAR, TDW, TWD,ORS	0.915	0.924	0.923	0.921
Sokoto	5	10,7,4,3,1	MAR, TDY, TWD, LRS, ORS	0.944	0.965	0.971	0.960

[1] PEV Code (i.e. 10=MAR, 9=MDL, 8= LDS, etc.) are as defined in Table 2 above

Source: Otun and Adewumi 2009

It should therefore be clearly stated that the emphasis of this study was not in the formulation of a 'one-in-all' index but rather seeks to prove that more PEVs can be included in drought index formulation for a semi-arid / arid regions of the world. This study has used equation 2 above as a model sample.

A new drought indexing method, CPEI, using PEVs has been proposed for quantifying the drought conditions and occurrences in any semi-arid or arid region. It is a pioneering approach that has shown that drought indexing in these regions is related to the use of several characteristics of precipitation and not only precipitation amount.

2.3.2.3.7. Analysis Of Dry Spells And Its Application To Crop Planning In The Sudano-Sahelian Region Of Nigeria

Otun and Adewumi (2009) reported the research work on rainfall variability and drought inference in Sudano-Sahelian Regions of Nigeria. The work examined the link between rainfall variability of the study area with the Sahelian drought using rainfall series from seven synoptic stations in the study area. The data covered 30 year climate interval (1940-1970 and 1970-2000. The percentage changes in mean monthly rainfall depth and number of rain days, ranged between 4 and 33 % for the core season and between 3 and 70 % in the marginal periods. The Standardized Rainday Index (SRI) and Normalized Rainday Index (NRI), two statistical descriptors, were defined and used in the study to highlight the variability in rainfall and infer drought occurrence in the study area. Both indices revealed that the temporal variability in amount and distribution of rainfall and number of raindays observed within the region have to a large extent contributed to the 1973 and 1984 drought occurrence in the region. Similarly, the relatively low NRI values observed within the region for the recent years may also be an indication that the drought conditions since the early seventies might be reoccurring.

A dry day and its sequence called dry spell is a useful proxy definition of drought condition or occurrence at a place. It simply connotes the absence of rain for a period in a locality. The characteristics of dry spell observed in an arid or semi-arid region, determines to a great extent what becomes of the few, scanty and poorly distributed rains usually observed in such areas (Wilhite, 2000; Adefolalu, 1986). Its impact on an environment cannot be over emphasized. Its occurrence and distribution over an area impinges and heavily undermines the effect of the previous rainfall occurrences (Otun, 2005).

The Sudano-sahelian region in Nigeria (SSRN) is a semi-arid region and lies between latitudes 10o N and 14o N and longitudes 3o E and 14o E as shown in below.

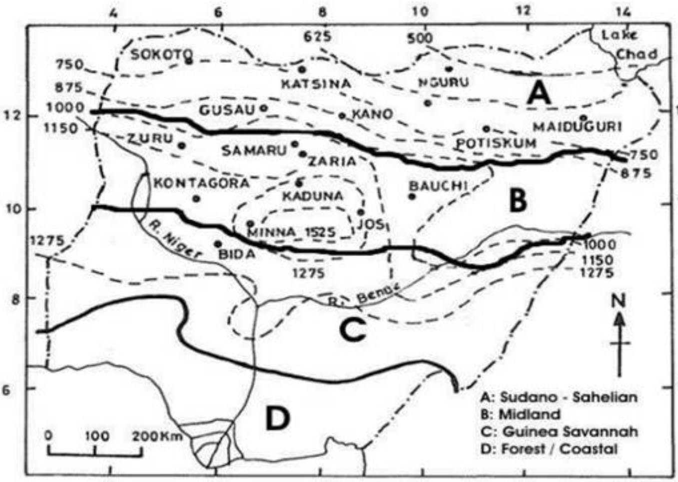


Figure 20 : Map of Nigeria Showing the Sahelian Region and the Synoptic Stations Used in the Study

Source: Otun and Adewumi 2010.

2. Dry spell analysis (DSA) and its applications. The empirical DSA approach proposed by Sivakumar (1992) for agricultural applications is being adopted in this study. It was however, slightly modified to include the following analytical steps and computations.

The application of this modified empirical DSA approach is expected to characterize the drought occurrences, as well as provide useful information on the inherent dry spell conditions that can be easily interpreted by crop planners and managers for effective coping and management of such dry spell anomaly. Such information is also useful for plant breeders in developing breeds or varieties of crops which can adequately cope with the various inherent dry spell conditions being evaluated.

Table 24: Probability of occurrence of dry and wet spells for various seasonal rainfall totals

	Percentage Occurrence of Dry and Wet Periods for each Seasonal Rainfall Totals (%)											
	1-Day		5-Days		7-Days		10-Days		15-Days		30-Days	
Station	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Gusau	80.9	19.1	57.1	42.9	53.0	47.0	49.3	50.7	46.4	53.6	40.5	59.6
Kano	84.0	16.0	62.1	38.0	58.9	41.1	55.1	44.9	51.9	48.2	45.7	54.3
Katsina	85.9	14.1	63.8	36.2	60.6	39.4	56.7	43.3	53.6	46.4	48.7	51.3
Maiduguri	86.1	13.9	64.3	35.7	60.4	39.6	56.7	43.3	52.1	48.0	46.8	53.2
Nguru	89.2	10.9	69.6	30.4	65.9	34.1	61.7	38.3	58.2	41.8	52.4	47.6
Potiskum	85.5	14.5	62.8	37.2	58.9	41.2	54.4	45.6	50.7	49.3	45.8	54.2
Sokoto	86.4	13.6	64.8	35.2	60.6	39.4	56.1	43.9	52.3	47.7	47.1	52.9

Source: Otun and Adewumi 2010.

Table 25: Probability of occurrence of dry spell occurrence within SSRN

	Probability of occurrence of Dry Spell (%)					
Months	< 2 days	3-4 days	5-6 days	7 – 8 days	9-10 days	>10 days
Jan	0.01	0.08	0.04	0.11	0.07	99.67
Feb	0.03	0.11	0.00	0.11	0.22	99.53
Mar	0.19	0.07	0.37	0.16	0.34	98.86
Apr	1.39	2.56	2.85	3.01	2.52	87.66
May	8.70	11.38	10.72	10.33	8.78	50.09
Jun	21.78	23.92	17.04	11.50	7.84	17.92
Jul	42.39	30.54	15.44	7.06	2.90	1.67
Aug	54.22	27.77	12.04	2.77	1.11	2.09
Sep	27.41	24.03	15.74	10.30	8.18	14.35
Oct	2.18	3.13	4.06	4.52	3.07	83.04
Nov	0.06	0.11	0.08	0.05	0.00	99.70
Dec	0.01	0.00	0.00	0.00	0.00	99.99

Source: Otun and Adewumi 2010.

The Onset of rains is often being used as a guide for selecting sowing dates for a year. The one major criterion for defining the onset of rains is usually when a cumulative of N-days rains is above a threshold (Stern et. al., 1981 and Sivakuma, 1992). The frequency distribution of the first dates of each year with cumulative of N-days rainfall above 10, 20 and 30mm were analyzed and used to obtain the most probable onset dates. Using N = 2 days (Stern et al. (1982), and with the assumption that a 80% probability of occurrence of this dates can be a guide to obtaining the most probable sowing dates; which turned out, by using Figure 19, to be 163rd day of the calendar year.

Table 26: Probability (%) of maximum and conditional dry spells exceeding indicating lengths within 30 days after a starting at SSRN

Decade / Date		Maximum Dry Spell Exceeding 5, 7, 10 and 15 days.							
		Maximum Dry Spell				Conditional Dry Spell			
		>5 Days	>7 Days	>10 Days	>15 Days	>5 Days	>7 Days	>10 Days	>15 Days
1	May	95	86	66	38	72	57	36	16
11	May	90	73	48	21	75	53	28	10
21	May	82	57	32	10	69	43	21	5
1	Jun	70	48	23	6	64	40	16	3
11	Jun	59	32	15	2	50	25	9	1
21	Jun	47	21	5	0	40	16	4	0
1	Jul	36	14	3	0	33	11	2	0
11	Jul	30	7	2	0	28	6	2	0
21	Jul	25	6	1	0	25	6	1	0
1	Aug	21	6	2	0	19	5	1	0
11	Aug	25	9	3	0	25	9	3	0
21	Aug	42	21	7	1	41	21	7	1
1	Sep	66	44	21	6	65	43	21	5
11	Sep	91	75	54	26	89	73	51	24
1	Sep	99	91	80	55	91	84	71	46
1	Oct	100	98	95	79	73	71	66	50

Source: Otun and Adewumi 2010.

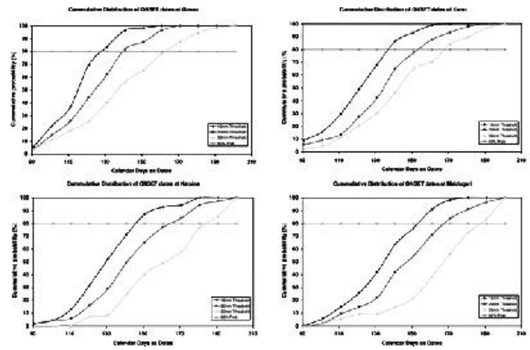


Figure 21 : Onset dates at Gusau, Kano, Katsina and Maiduguri Stations for different rainfall thresholds

Source: Otun and Adewumi 2010.

Using a 30 mm rainfall depth threshold as defined by Stern et al. (1982), (obtained by simple interpretation of Figure 12), the results provide a good idea of the average rainfall pattern during the crop cycle at each station under study. For SSRN, assuming that a pearl millet variety of a 90-day maturity duration comes to panicle initiation stage within 20 days after sowing (DAS) and to the flowering stage by 50 - 60 DAS, mean rainfall from sowing to panicle initiation stays around 59 mm per decade and increases to 86 mm per decade by the time of flowering. The deductions that can be made from the 90% probability column of Table 8 is that, for each consecutive 10-day period after sowing, the dry spell with 90% chances or occurrence, will end within the number of days given in Table 8.. Using the earlier example given above, at 50 DAS, for the 10-mm rainfall threshold, 90% of the dry spells will end in 7 days or less, while 75% of the dry spells will end in about 4 days or less.

Specifically, the study has been able to provide empirical basis or tool for effective management of the drought in the Sudano Sahelian areas of Nigeria. This can also act as a drought management support tool for proposed National Drought Monitoring Plan in Nigeria.

2.3.3. Capacity Building Network Approach to Integrated Water Resources Management

According to Adewumi *etal*.,(2011), the state of Integrated Water Resources Management(IWMI) into the development of water in order to ensure sustainability. This is only possible if existingCommunity-Based Institutions (CBIs) develop a sustainable collaboration with agencies of renewable water development and management.During the study, they stated the importance of incorporating the curriculum of water related courses in the CBIs this will adequately furnish the concerned stakeholders the necessary information and knowledge base for the challenges of the new ways to establish a national Water Resources Capacity Building network for everyone to embrace. The network will enable all stakeholders in the water sector to synergize and share information that will be required to tackle the problem of water at hand and manage the resource of water in a sustainable manner.

2.3.4. Quality Evaluation of Household wastewater for irrigation

In the assessment of household wastewater for irrigation efforts, Musa *et al*., (2011) affirmed that water was becoming an increasing scarce resource. They stated that planners should consider other sources of water for the purpose of irrigation which might be used economically and efficiently to promote further development in the area of agricultural productivity. They suggested that irrigated agriculture occupied approximately 17 % of the world's total food production. Whenever good quality water is scarce, water of marginal quality has to be considered for use in agriculture. It was reasoned that domestic wastewater varies in composition from place to place due to different water sources used and also the composition and soil minerals from these sources. Using ten samples of waste water collected from kitchen, laundry, and toilet and other similar sources, the authors came up with a result of chemical, physical, metallic and non-metallic analysis and arrived at a conclusion that if mini treatment outfits could be established for household units, it will be possible to recycle most of our wastewater for irrigated agriculture.

Tables 27, 28, and Table 30 below presents the various domestic water considered for the study.

Table 27: Chemical Analysis of Toilet Wastewater Samples

S/ No	Parameters	Samples T										
		A	B	C	D	E	F	G	H	I	J	Average
1	pH	6.3	5.7	6.4	6.5	6.7	6.67	6.73	5.23	9.43	9.79	6.92
2	Con (dS/cm)	7.9	6.6	6.5	5.3	7.5	8.6	7.845	7.654	8.756	7.946	7.46
3	BOD (mg/ *l*)	126	134	143	125	125	126	124	119	122	123	126.7
4	COD (mg/ *l*)	192.5	191.8	191.9	191.8	191.9	191.7	191.68	191.52	190.98	192.34	191.8
5	TH (mg/L)	76	78	79	76	76.5	77	76.8	74	75	78	76.63
6	Alk (mg/ *l*)	215	216	218	218	220	214	213	216	215	212	215.7
7	Na (mg/ *l*)	143.9	138.	141.9	140.6	142.3	143.7	143.89	142.99	143.98	143.82	142.55
8	K (mg/ *l*)	48.3	44.22	41.6	50.01	49.7	48.3	48.29	48.44	47.49	48.98	47.5
9	Mg (mg/*l*)	16.3	11.2	13.2	17.5	14.3	15.6	14.35	15.63	13.45	12.98	14.4
10	Mn (mg/ *l*)	0.05	0.1	0.2	0.3	0.3	0.08	0.10	0.20	0.18	0.19	0.17
11	Cu (mg/ *l*)	0.1	0.4	0.6	0.8	1.1	1.3	0.56	0.87	0.97	1.01	0.788
12	Fe (mg/ *l*)	0.3	0.3	0.4	0.4	0.4	0.4	0.35	0.42	0.37	0.33	0.372
13	Pb (mg/ *l*)	0.4	0.3	0.5	0.4	0.4	0.4	0.28	0.34	0.26	0.49	0.38
14	Zn(mg/ *l*)	4.0	4.1	4.7	3.9	4.0	4.6	4.5	4.8	4.2	3.4	4.22

Musa, et. al., 2011

Table 28: Chemical Analysis of Kitchen Wastewater Samples

S/ No	Parameters	Samples K										
		A	B	C	D	E	F	G	H	I	J	Average
1	pH	5.69	5.65	5.62	5.67	5.76	5.45	5.68	5.68	5.69	5.71	5.66
2	Con (dS/cm)	2.560	2.479	2.539	2.547	2.562	2.567	2.576	2.564	2.559	2.557	2.551
3	BOD (mg/ l)	48	48.70	48.12	48.13	47.96	48.01	48.05	48.98	48.02	49.51	48.348
4	COD (mg/ l)	124.12	123.87	124.02	124.11	124.11	124.14	124.08	124.13	124.07	124.09	124.074
5	TH (mg/L)	198	200	199	198	190	197	196	196	197	198	196.9
6	Alk (mg/ l)	480	481	479	487	481	478	479	482	483	481	481.1
7	Na (mg/ l)	176.09	178.93	178.99	176.93	176.53	176.42	176.36	176.24	176.11	176.08	176.868
8	K (mg/ l)	62.60	62.57	62.45	62.76	61.99	63.07	63.17	62.97	62.67	62.69	62.694
9	Mg (mg/l)	9.07	8.97	8.99	8.89	9.02	9.04	9.08	9.06	9.09	9.05	9.026
10	Mn (mg/ l)	0.28	0.27	0.27	0.30	0.29	0.31	0.29	0.29	0.27	0.28	0.285
11	Cu (mg/ l)	0.13	0.11	0.10	0.09	0.08	0.12	0.11	0.10	0.14	0.13	0.111
12	Fe (mg/ l)	0.50	0.51	0.58	0.59	0.58	0.51	0.53	0.52	0.50	0.48	0.53
13	Pb (mg/ l)	0.3	0.2	0.3	0.28	0.31	0.34	0.29	0.32	0.30	0.31	0.295
14	Zn(mg/ l)	4.5	4.8	4.6	4.2	4.3	4.9	4.6	4.7	4.4	4.3	4.53

Musa, et. al., 2011

Table 29: Chemical Analysis of Laundry wastewater samples

S/ No	Parameters	Samples L										
		A	B	C	D	E	F	G	H	I	J	Average
1	pH	4.22	4.67	5.78	4.76	4.97	4.98	4.33	4.35	4.21	4.20	4.647
2	Con (dS/cm)	4.220	4.230	4.234	4.267	4.235	4.234	4.342	4.135	4.236	4.354	4.2487
3	BOD (mg/ l)	66.30	65.45	67.23	67.46	65.54	65.67	67.01	68.00	67.78	67.47	66.791
4	COD (mg/ l)	168.20	167.20	167.23	166.75	167.64	168.36	167.45	167.16	165.67	168.21	167.387
5	TH (mg/L)	336	342	340	338	337	329	327	328	342	332	335.1
6	Alk (mg/ l)	426	436	435	426	476	436	425	453	436	427	437.6
7	Na (mg/ l)	198.32	198.22	197.47	198.22	198.45	198.56	197.07	198.06	198.27	198.46	198.11
8	K (mg/ l)	84.22	84.32	84.47	84.46	84.41	84.49	84.45	84.98	83.99	83.96	84.375
9	Mg (mg/l)	37.36	36.79	36.75	36.98	36.96	36.94	36.99	37.25	37.34	37.39	37.075
10	Mn (mg/ l)	0.02	0.01	0.02	0.02	0.10	0.07	0.01	0.02	0.03	0.02	0.032
11	Cu (mg/ l)	0.30	0.29	0.27	0.31	0.33	0.30	0.33	0.30	0.31	0.31	0.305
12	Fe (mg/ l)	2.80	2.82	2.79	2.78	2.77	2.87	2.81	2.84	2.82	2.81	2.811
13	Pb (mg/ l)	0.9	0.87	0.88	0.88	0.91	0.93	0.92	0.92	0.91	0.87	0.899
14	Zn(mg/ l)	4.4	4.1	4.3	4.6	4.7	4.6	4.8	4.4	4.2	4.2	4.43

Musa, et. al., 2011

It was concluded that direct use of domestic wastewater (untreated wastewater) may not be healthy for agricultural purposes except it undergoes certain wastewater treatment process. Poor quality water may affect irrigated crops by causing accumulation of salts in the root zone, thus affecting the permeability/uptake of water from the soil to the plants. Contaminants in irrigation water when it accumulates overtime in an agricultural soil renders such soils unfit because of the accumulation of salts and other heavy metals present in the soil; thus, reducing arable crop farming in agricultural activities.

For wastewater to be useful for arable crop farming there are several options for which the farmer can use to improve its quality one of whichis that the farmers blend the treated waste water with the conventional sources of water, canal water or groundwater, if multiple sources are available.

It is possible that a farmer may have saline groundwater and if the farmer has non-saline treated wastewater, the two sources of water could be blendedtogether to an acceptable salinity level. Furthermore, by blending, the microbial quality of the resulting mixture could be superior to that of the unblended wastewater. Another is the creation of on-farm drainage systems to channel away from the farmland excess/wastewater hence reducing the salinity level and lowering the water table to a desirable level, at which it does not contribute to the transport of salts to the root zone and the soil surface by capillarity.

Another strategy is to use untreated wastewater alternately with treated wastewater, canal water or groundwater, instead of blending. From the point of view of salinity control, alternate applications of the two sources will be superior to blending. However, an alternating application strategy will require dual conveyance systems and availability of the effluent dictated by the alternate schedule of application.

2.3.5. Water Resources Management of Jamaare And Misau Rivers Sub-Catchment of Komadugu Yobe River Basin

Sobowale and Adewumi in 2008 investigated the water management practices in Jamaare and Misau Rivers Sub-Catchment of Komaduru, Yobe River Basin in Nigeria.They worked on water audit and water demand analysis and discovered that data collected were consistent between 1971 and 1992 but was not thereafter as a result of the drought that occurred in the area. As a result of which recorded mean annual runoff (MAR) at Bunga, Foggo and Katagun on the Jamaare river was 1693 million cubic meters (MCM), 2056 MCM and 1713 MCM respectively. The MAR Misan RiverKari was 324 MCM, this reduced to 135 MCM at Dapuchi station. The total analysis of the river situation revealed that the available water in the catchment was able to meet the water demand at the initial time but the sites started to slide into conditions of water scarcity with the advancement of time.

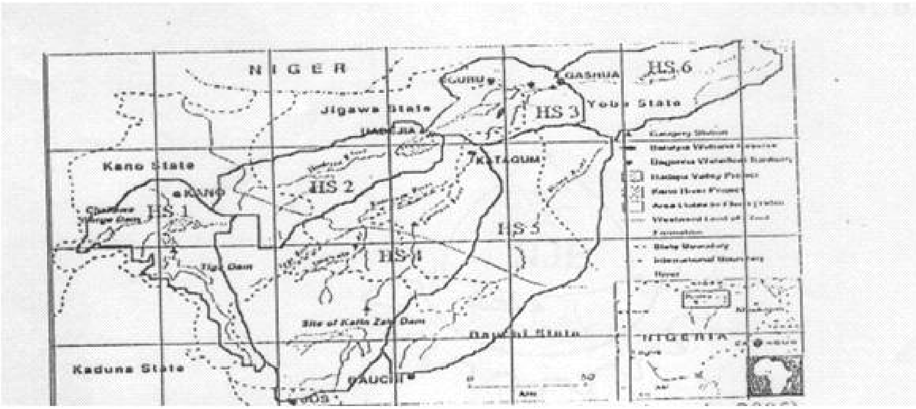


Figure 22: Map of Komadugu Yobe River basin (Sobowale, 2005)
Source: Sobowale et. al., 2008

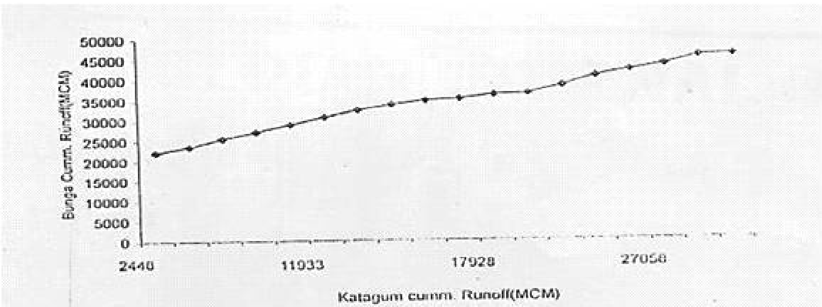


Figure 23: Double mass curve for Bunga and Katagum stations on Jamaare River
Source: Sobowale et. al., 2008

Sobowale *et al* (2008) conducted a survey of the productivity of some water wells in the Alluvial Sediments of Lake Chad. The survey covered10 water boreholes using drawdown test. Also observed were, the hydraulic characteristics, the transitivity and the tap of the aquifer using regression analysis technique. The survey recorded a result of specific capacity of the well in the range of 9.3 -26.1 m^2/day, aquifer loss ranges from 1.61 – 10.57 m, well loss range between 0.25 – 4.40m, while transmisivity of the tapped aquifer was between 13 -35 m^2/day. The efficiency of the wells was evaluated to be between 51.1 – 89.1 % It was concluded that the efficiency was satisfactory and that the wells were still performing but the performance must be improved upon in order to guarantee continuous supply in the future.

The results of this study estimated the available surface and groundwater resources of the Jamaare and Misau Rivers sub catchment of the Komadugu, Yobe River basin. The projected trend of water resources development in the area showed that the current development rate is not sustainable as demand will clearly overshoot supply by the year 2020. An Integrated Water Resources Management (IWRM) should therefore be pursued to ensure sustainability. It is also advised that radical water demand management be applied. Efforts to discourage uneconomical use of water resourcesbe aggressively pursued through sensitization and advocacy.

2.3.7 Stormwater Characteristics on 3rd Mainland Bridge Lagos, Nigeria

Adekunle et. al., (2012) reported the study of the storm water characteristics on 3rd mainland bridge Lagos Nigeria. They stressed that storm-water from highways contained pollutants from vehicle emissions such as heavy metals, oil and grease. They selected 5 study points along the bridge and monitored the storm-water flow from the sections for three years. They analyzed the water samples collected using standard procedures. They also carried out inter-parameter correlations of EventsMean Cconcentrations (EMC). They used Best Management Practices (BMPs) to assess the concentration reduction in the Storm Water. At the end of the study,it was concluded that the major pollutants in the storm-water were within acceptable limit. They noted that the turbidity of the storm-water was very close to the upper limit of the threshold. They noted also that the water was particularly polluted with organic matter load and heavy metals.

2.3.8 Performance Evaluation of Dry Season Okra under Sawdust and Trash Mulch Cover Treatments in Southwestern Nigeria

Oladipo *et. al.,* (2013) reported the experimental investigation of the agronomic performance of okra under various quantities of both sawdust and trash mulches. This was among many strategies for managing water use in agriculture. The experimental design used was complete randomized design with 6 treatments on both specimens. The experiments were repeated the following year on the same plot but with transposed plot allocation. Soil moisture loss from uncovered plot was with the highest value dropping to less than 2 per cent. It was followed by that of trash plot and the lowest loss was on sawdust mulched plot.

The number of leave formed by okra on sawdust, trash and no mulch plots were 43, 36 and 27 respectively while maximum girth diameter was 37 mm in both trash and sawdust covered plots but okra plant on control plot attained only 26 mm diameter. Fruit yield were almost similar to trash and sawdust mulched okra having 7.5 and 7.6 Tonnes/Ha respectively while control plot recorded 5.2 Tonnes/Ha. The ash content of dry matter of sawdust, trash and no mulched plants was 0.25, 0.20 and 0.17 kg respectively. It was concluded that sawdust could perform as much as the traditional trash materials commonly used in Southwestern Nigeria and that it could serve as good material for conserving soil moisture.

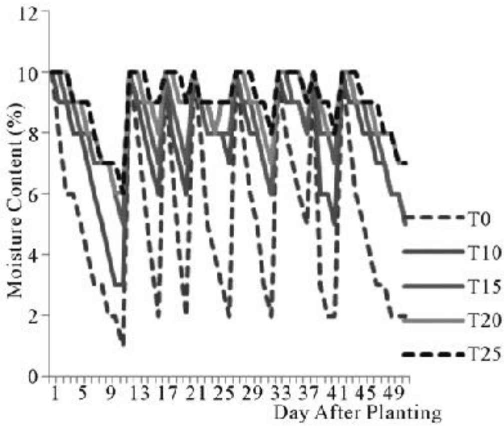


Figure 24: Soil moisture conservation under various quantities of trash mulch.
Source: Oladipo et. al., 2013

2.3.9 Design Construction and Evaluation of An Affordable Continuous – flow Drip Irrigation System

Adewumi et al (2004) reported a work on design and evaluation of an affordable continuous-flow drip irrigation system. The work was targeted at Bauchi agricultural environment and the test crop was tomato.

The system was design to deliver the peak daily crop water requirement on a continuous basis throughout the day. The calculated continuous flow rate was 9 drops of water per minute. The hydraulic design was based on a step wise use of the energy equation. The system was constructed exclusively from cheap and locally available materials incorporating a modified form of the medical infusion set as emitter. Results of the system's evaluation revealed high Application Efficiencies in the order of 95, 96, and 98 % under continuous discharge of 9, 13, 17 and 21 drops per min respectively. The system which was said to be able to irrigate 288 stands of vegetable was completed with a total initial cost of 350 USD. The team concluded that the developed system could be a reliable and affordable system for farmers who want to increase their production at low cost.

2.3.10 Yield of tomato grown under continuous-flow drip irrigation in Bauchi state of Nigeria.

Adewumi et al (2006) studied the yield of tomato grown under continuous flow drip irrigation system in Bauchi. It was averred that current global concern of food security and poverty alleviation requires new strategies with marked potential for water conservation and yield increase. They suggested a design of an affordable continuous flow drip irrigation system that applies the exact peak crop water requirement continuously throughout the 24-hr of the day and so keeps the root zone of the crop near field capacity all through the growing season. The design continuous flow rate was 9 drops per minute i.e., 0,03 l/h for tomato used as test crop. The above project and results led us for a competitive research grant from Agricultural Research Council of Nigeria (ARCN) that gave N36million grant. The Research station was both FUNAAB and ATBU.

The system was constructed from inexpensive off the shelf components, incorporating the medical infusion set as emitters. The drip system was evaluated under 4 continuous-flow rates of 0.03, 0.05, 0.06 and 0,07 l/h against a bi-daily application as control. The recorded yields were 42.9, 42.6, 44.4 and 44.4 t/ha respectively for the four treatments and 22.3 t/ha for the control plot. The recorded associated water use Efficiency were 15.5 x 10^2, 10.7 x 10^2, 8.5 x 10^2 and 6.4 x 10^2 t/ha-mm in the same order for the 4 treatments and 10.1 x 10^2 t/ha-mm.The system offered water saving values of about42.3 and 15.7 % at 0.03 and 0.05 l/h respectively over short level impoundment furrow irrigation widely used in the resource poor farmers in the study area and Nigeria generally. The team concluded that the study demonstrated a promising prospect of the affordable irrigation system in delivering high crop-yields especially if the crops are grown under appropriate agronomic practices that enable protection of the growth season. They recommended a continuous dripping of 0.03-0.05 l/h for tomato in Nigeria.

Plate 13: Field Layout of Continous Drip Irrigation (ARCN) Project at COLENG Farm

Source: Adewumi *et.al.,* 2010

Plate 14 : Result of Precise Affordable Drip Irrigation ARCN Project
Source: Adewumi *et.al.*, 2010

2.3.11. Crop Coefficient of Corn (zea mays) as influenced by water table depths under green house culture.

Report of greenhouse lysimeter experiment to observe the influence of ground water table on the crop coefficient of maize was presented by Egharevba et. al., 2005. Constant water table was maintained in a lysimeter at 300, 450, 600 mm. Water was applied at the surface (irrigation) at 5 day interval. Crop coefficient (Kc) at different growth stages were determined using Blaney-Morin-Nigeria evapotranspiration model and actual corn water use measured from green house experiment. The study showed that water depth at 450 mm gave the maximum water use efficiency of 1.5 kg/ha-mm. The Kc values at 450 mm water depth obtained at different stages of corn development ranged from 0.5 at emergence to a peak value of 1.06 at flowering stage. The value later dropped to 0.7 at harvest stage. The Kc values obtained can be use for planning, design and operation of irrigation system in the inland valley within the moist Guinea Savannah Zone of West Africa, the team concluded.

2.3.12. Physicochemical Assessment of Groundwater as a Source of Domestic Water Use in Some Selected Settlements in Minna, Niger State

Adewumi et al (2011) conducted the physico-chemical assessment of groundwater as a source of domestic water used in some selected settlements of Minna in Niger State Nigeria. Lack of safe drinking water and adequate sanitation measures lead to a number of diseases such as cholera, dysentery, salmonellosis, and typhoid, and every year millions of lives are claimed in developing countries. Some rural and major populations are heavily dependent on small reservoirs, other sources of their water supply, and are concerned about the quality for direct consumption and other uses. Water samples from different areas i.e. within Minna were collected and tested for their chemical and physical parameters. It was discovered that all the water samples had a common room temperature of 29.1 ^{o}C. Sample f had the highest electrical conductivity of 560u/cm and sample A had the lowest value of EC. Sample F had a higher value of 280 mg/l of total dissolved solid while sample A had the lowest. The pH of the samples fluctuated greatly with sample A and F. having the lowest value of 6.8, while sample G had the value of 7.4 though they all were still within the range. Sample C, E, and F, were within the maximum permissible limit of 5.0 when turbidity was analysed. It was also observed that sample H had the highest value of Nitrate content (6.2) which was closely followed by sample F, while sample B had the lowest value of 0.3. It was concluded that the water quality for some of the samples was contaminated due to lack of proper treatment thus endangering the lives of the consumers.

2.3.13. Hydraulic Performance Evaluation of the distribution system of Hadejia Valley Irrigation Project

Effects of irrigation network deterioration on water distribution, productivity and environment in Kano River Irrigation Project. (KRIP) A network survey of water canal system and hydraulic structures was conducted in 3 sectors located at upstream, middle and tail end of KRIP. Duringthe dry season of 2003/04.Secondary and tertiary levels of the network was surveyed A team was used for each sector. The result showed that from 4 distributarycanals (DC) two were heavily silted (>60% silt) and the other 2 were moderately silted (30-59% silt) while weed infestation ranged from 25-75 %. Out of 24 field channels (FCs), 50 % of the cross regulator (CRs) and 66 $ of the field channel outlets (FCOs) were damaged while more than 70 % of the drop structure (DSs) were also damaged. Similar results were recorded for the other 2 sectors. The consequences of this network and structures deterioration on water conveyance and distributions include reduction of the reduction of the carrying capacity of the west branch canal from 22.5 m/s in 1996 to the barest minimum of 7 m/s in 2002. A reduction in the cropped area from 12700 Ha to mare 2350 Ha in the same period was observed.

Plate 15: Evidence of deteororation of distributary canal (bad maintenance)

Plate 16: Evidences of salinity build up and water logged conditions due to poor maintenance and poor drainage system. Source: Abubakar et. al., 2001

Evidences of salinity build up and water logged conditions in some of the sectors were observed. Water table rise from about 70 cm to 40 cm within 10 years in Kadawa sector was reported. This had evidently affected yields of most crops in the project. The implications of these problems are low equity and inadequacy in water distribution, which may shorten the lifespan of the project and lower productivity. The paper discusses causes of deterioration, their implications to water management, crop productivity and sustainability of the project.

2.3.14. Physicochemical Assessment of Groundwater as a Source of Domestic Water Use in Some Selected Settlements in Minna, Niger State.

Adewumi et al., (2011) proposed a sustainable groundwater recharge method using runoff catching mechanism. The study recognized the importance of water in the global system. It ex-rayed the estimated quantity and over-abstraction of groundwater around the world and the threats such practice holds for humanity.

The work suggested the harnessing of runoff water often left to waste away to replenish groundwater reserve. The design included the homestead recharge system and the cumulative global recharge system.

2.3.4. The Impact of Flooding to Agricultural Production and Food Security in Nigeria.

The recent effect of climate change in Nigeria and the increased competition for Land and water are likely to increase vulnerability to food security, in Africa and particularly in Nigeria FAO 2013. This is as a result of weather changes and high intensity of rainfall resulting to flooding in most part of Nigeria. The states mostly affected in the year 2022 are: Imo, Jigawa, Balyelsa, Delta, Lagos, Bornu, Adamawa, River, Kogi, Yobe, Anambra states and some part of Kwara, Benue and Niger States. The imperative for such flooding and agricultural growth is strongest in developing countries, tropical region of Africa particularly Nigeria. The implication of the above information and with this development, even if agricultural production (cereals grain grown areas of Nigeria) doubles by the year 2050, one person in twenty risks being undernourished equivalent of more than 390 million in Sub-Sahara Africa (FAO, 2013)

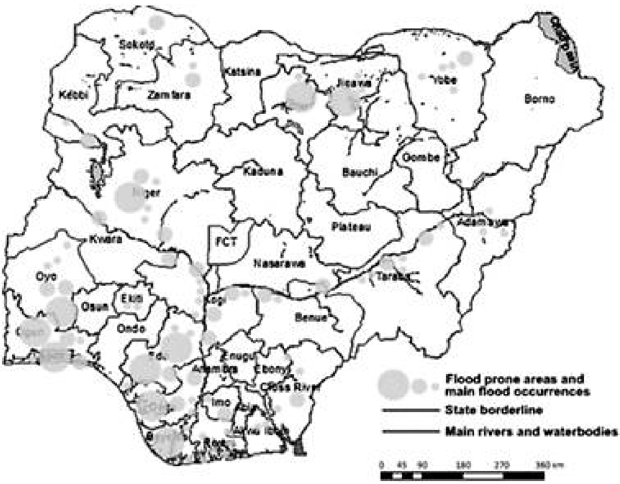


Figure : Flood prone areas in states in Nigeria
Source: NTA Network News (9.00pm – November 13th, 2022)

In the face of devastating flood effect this year (2022) and last Year 2021, measures to raise agricultural crop output and strengthen food security in the face of wasted agricultural field across the states where these flooding is rampaging is of serious concern and the measure taking by government is not enough. Instead, government is busy distributing relief materials, such as clothing, foods and were relocated to what we now call Internally Displaced Persons (IDP) for the affected community instead of providing solution to annual flooding experienced. Several such IDP has been created across affected states. The end result is starvation and famine. The effect of this flooding is contributing to slow rates of growth in agricultural production in the affected part of the country. In Nigeria alone, over 2.9 million were displaced in the year 2021, 600 deaths, and over 600,000 hectares of lands farm lands affected and destroyed with over 123, 000 houses destroyed. The agency created for this purpose call NEMA (National Emergency Management Agency) are charged with distributing Palliatives assisted with the state government in most states. This year 2022 over one million has been displaced, more than 2776 persons were injured, more than 12 states has been affected by this flood with Jigawa, Balyesa and River States mostly hit.

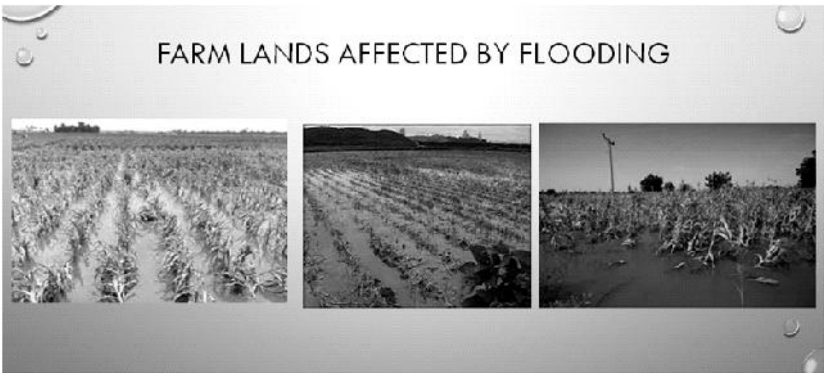


Plate 17: Maize farm ravaged by flooding, October, 2022
Source: NTA Network News (9.00pm – November 13th, 2022)

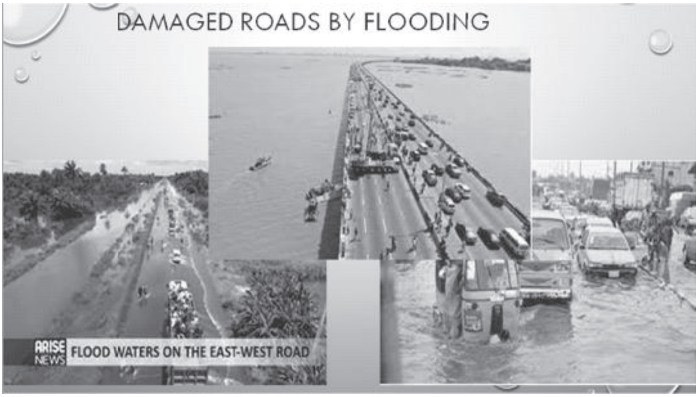


Plate 18: East-West Road, Lagos and Lokoja River Niger Bridge Flooded October, 2022
Source: NTA Network News (9.00pm – November 13th, 2022)

In addition, Nigeria East-West Road was cut off by ravaging flood causing motorist serious hardship and Lokoja Abuja high way was flooded across River Niger causing a lot of motorists stranded for weeks. Presently, federal Government of Nigeria, United Nations and states government are planning to address the flood problem in Nigeria. The problem is devastating and heart breaking as reported by Nigeria local news channels (the NTA, TVC and Channels news mostly).

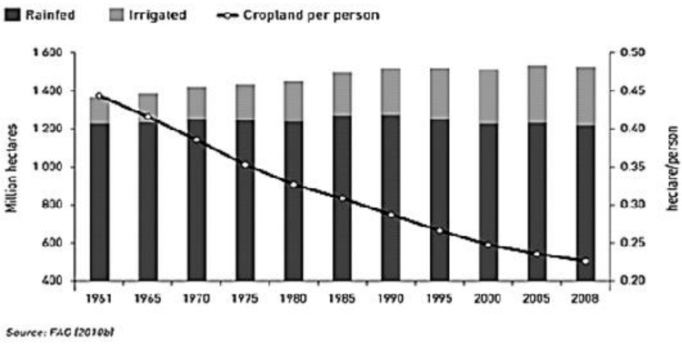


Figure 25: Evolution of land under rain fed and irrigated cropping (1961-2008)
Source: FAO, 2010b

In the face of this flooding, water scarcity is growing, Salinization and pollution of water courses and bodies, and degradation of water-related ecosystems are rising. The agricultural farm land has been drastically affected.

Agriculture should be a major contribution to Nigeria GDP, but the effect of flooding as a result of climate change brings an increase in risk and unpredictability for farmers – from warming and related aridity, from shifts in rainfall patterns, and from the growing incidence of extreme weather events in the last 15 years. Poor farmers in low-income in the affected areas of Nigeria are the most vulnerable and the least able to adapt to these changes.

The deteriorating trends of flooding in the capacities of ecosystems to provide vital goods and services are already affecting the production potential of important food-producing zones (cereals grain). If these continue, impacts on food security will be greatest in developing countries like Nigeria, where both water and soil nutrients are least abundant to support the crop.

Presently, the world's cultivated area has grown by 12 percent over the last 50 years. The global irrigated area has doubled over the same period (SOLAW). Agriculture already uses 11 percent of the world's land surface for crop production. It also makes use of 70 percent of all water withdrawn from aquifers, streams and lakes.

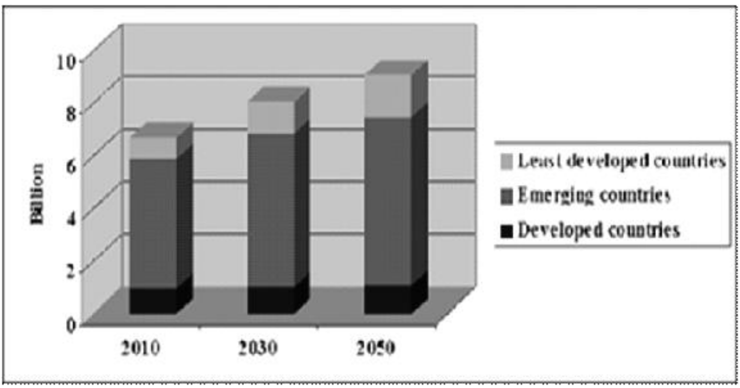


Figure 27: World Population and poverty level
Source: FAO, 2011

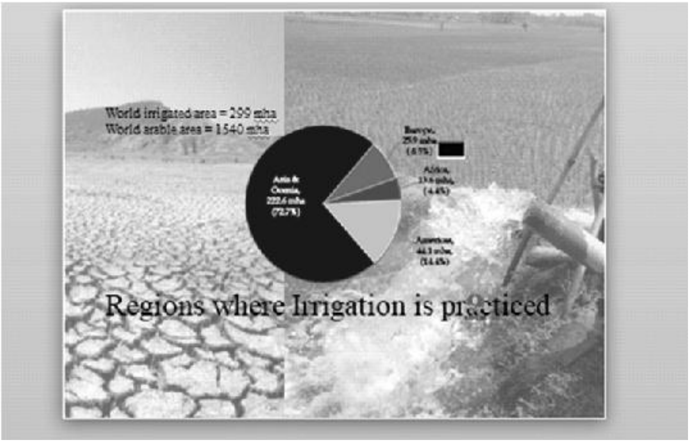


Plate 22: Regions where Irrigation is Practiced (World wide)Source: FAO, 2011

Agricultural policies have primarily benefitted farmers with productive land and access to water, bypassing the majority of small-scale producers who are still locked in a poverty trap of high vulnerability, land degradation and climatic uncertainty (SOLAW). Toward 2050, rising population and incomes are expected to call for 70 percent more food production globally, and up to 100 percent more in developing countries. The prevailing patterns of agricultural production in Nigeria particularly in the most affected areas by flooding, need to be critically reviewed by advising local farmers affected by this flood in training them the water harvesting techniques in the agricultural fields particularly by creating a depression where it is necessary and establishing contour bund in the valley areas to intercept the runoff thereby reducing effect of impact of this excessive runoff on the agricultural fields damaging crops and render thousands inhabitant homeless. Using this water harvesting techniques will increase the farmers productive capacity under a combination of excessive demographic pressure and unsustainable agricultural practices in the valley areas prone to flooding.

In addition to adopting field water harvesting techniques, Irrigation practices should be introduced to allow farming activities during the dry season period (the northern part of the country is where irrigation practice is predominant). It is very disheartening to note that the northern part of the country is mostly affected where rainfall is less than 4.5 months in a year.

2.3.4.1 Review of Public Irrigation Sector (North West)

This is a commission project by UNFAO through ENPLAN GROUP of Companies. After extensive field work of the RBDAs in the Northwest Zone, certain parameters were adopted in Ranking the projects, they include: Technical, Agriculture, Socio-economic, Location and Environmental aspects of the projects. In general, we made some recommendations to FAO to the Federal Government of Nigeria. Few of them are listed below.

- The entire projects visited need an exercise that will lead to the reduction of staff strength in the RBDAs, retaining the qualified ones in Participatory Irrigation Management and laying off the others. RBDAs should also have a level of autonomy in decision-making on their individual scheme. Farm machineries, like tractors and implements among others can be sold out to farmers or farmer's organization on loan through RBDA.
- A comprehensive organization of WUA is very vital to the success of any irrigation project. There is a need to prepare them to assume full responsibility for operation and maintenance of the scheme.
- The Federal Government of Nigeria must out of good will release grants for rehabilitation of these projects for onward privatization and joint management as the case may be.
- We recommend the establishment of rural courts in project areas with frequent conflicts particularly between farmers and herdsmen. Conflicts of farmers with herdsmen have been recognized as a serious socio-economic factor that can affect production and productivity of any scheme. The present of such court will reduce conflict and provide security for farmers who cultivate crops under irrigation.
- For any realistic sustainable efforts, irrigation project must be made to be participatory and decentralized. This will

encourage locally driven assistance which produces sustainable impacts over the long term.

- RBDAs need to be restructured in such a way that it should be client-centered. This will ensured that demand is met and the RBDA field workers adequately support community self-management. RBDAs staff must have a high level training in handling community based projects and rural life development.

2.3.4.1.1 Selected River Basin Development Authority irrigation structures visited

Plate 19: Main Canal at Bakolori Irrigation Project (Talata Mafara) Zamfara State
Source: Adewumi et. al., 2005

Plate 20: Zauro Polder (Pilot Scheme) Irrigation Project (Kebbi State) – Poorly maintained
Source: Adewumi et. al., 2005

Plate 21: Main Canal – Jibiya Irrigation Project (Katsina State) Poorly Maintain
Source: Adewumi et. al., 2005

Plate 22 : Jibiya Irrigation project (Connecting Niger Republic) Katsina state
Source: Adewumi et. al., 2005

2.3.4.2 National Agricultural and Land Development Agency(NALDA)

During the period between 1995 – 2000) Institute for Agricultural Reseach (IAR) in Samaru-Zariawas awarded few NALDA project to produce the map, soil survey, layout design of the farm to be divided into 0.4ha per farmer. I was opportuned as an Agricultural Engineer to have Participated in the Design of Farm road and Layout ofproject in following States: Kano State (Tiga), Kaduna State (Birnin-Gwari and Manchok), Taraba State (Bali), Anambra State (Awka), Jigawa State (Hadejia), Kebbi State – (Kaoje).

3.0 CONCLUSION

Raindrops are major cause of soil splash at the earth surface and make the soil loose and susceptible to soil erosion, and that no rainfall events have the same intensity. Therefore, dislodgment of soil particles from their original location is caused primarily by forces of rainfall drops impact on the soil particles causes erosion to occur easily implying that both natural rainfall and rainfall simulator observed that the amount of rainfall and its intensity resulted in the amount of soil so detached indicates that the higher the calculated rainfall intensity and rainfall kinetic energy, the greater the amount of soil detached from bare soil into erosion. That soil detachment by rain drop-impact decreases exponentially as the water depth increases. Empirical relationships to calculate intensity of rainfall (mm/hr) and kinetic energy ($J/m^2/mm$) was established for the area.

The FUNAAB soil is quick draining with high infiltration rate and very poor water retention capacity confirming that the soil will require a short irrigation interval of about two to three days since available water for plant growth in predominantly sandy soils ranges between 2%-8%. Based on the foregoing, sprinkler irrigation is best suited for the IWO soil series but drip irrigation will minimize the use of excessive water. It should however, be noted that the water application rate must be less than the infiltration rate of the soil in order to prevent surface ponding and runoff.

An empirical relationship was established as a basis or tool for effective management of the drought in the Sudano-Sahelian areas of Nigeria. This can also act as a drought management support tool for proposed National Drought Monitoring Plan in Nigeria.
Based on the knowledge of erodibility index of the soils evaluated, ability to know the amount of Soil Loss (Erosion) in a field for a particular rainfall event can easily be measured, which will guide soil conservation engineer for appropriate Terrace method to be

adopted in order to reduce erosion rate on the field.

In the area of rainwater harvesting, it was established that water storage facilities in a depression exist (either created naturally or artificially) and was available in the field which sometimes can last between three to four months in the semi-arid region of Nigeria. This water serves both the farmer and the herders during the critical period of no rainfall of the year.

In the area of Climate Change, the increasing trend in minimum temperature and maximum temperature implies an increase in evapotranspiration across West Africa sub-region which is of great concern to crop producers. Rainfall and temperature are climatic variables mostly affected by global warming.

In the area of Irrigation and food security, it has been established that for Nigeria to achieve the food security component of Millennium Development Goal (MDG), there is a need to consider an elaborate irrigation practice with optimal water use efficiency. In other words, there should be farming throughout the year. (during rainfall and during the dry period by the use of full irrigation, supplementary irrigation and water harvesting techniques). The design of an efficient irrigation and soil drainage system for increased crop production requires the understanding of the dynamics of soil moisture and its availability for crop growth and development.

4.0 RECOMMENDATIONS

Federal Government of Nigeria should help the Farmers through an extension agents in ministries, education sector and Local Government areas of the country to construct an effective conservation measures before any rainstorm causing flooding e.g. construction of drainage around their farms, establishment of contour bunds, construction of conservation measures and water harvesting techniques to alleviate problem of flooding every year and loss of valuable farm produce to control possible famine in

view of climate change trends. The water harvesting suggested the harnessing of runoff water often left to waste away and destroying farmer's agricultural field in terms of flood and further to replenish groundwater reserve in the area of extreme drought.
The Federal Government of Nigeria must out of good will release grants for rehabilitation of these projects for onward privatization and joint management as the case may be for all the River Basin Development Agency. (RBDA)

Conflicts of farmers with herdsmen have been recognized as a serious socio-economic factor that can affect production and productivity of any scheme. Federal Government is advised to established grazing areas for farmers that are not under RBDAs.

For any realistic sustainable efforts, irrigation project must be made to be participatory and decentralized. This will encourage locally driven assistance which produces sustainable impacts over the long term.
RBDAs need to be restructured in such a way that it should be client-centered. This will ensured that demand is met and the RBDA field workers adequately support community self-management. RBDAs staff must have a high level training in handling community based projects and rural life development.
The prevailing patterns of agricultural production in Nigeria particularly in the most affected areas by flooding, need to be critically reviewed by Federal Government of Nigeria by advising local farmers affected by this flood in training them in the area of water harvesting techniques in the agricultural fields particularly by creating a depression where it is necessary and establishing contour bund in the valley areas to intercept the runoff thereby reducing effect of impact of this excessive runoff on the agricultural fields damaging crops and render thousands inhabitant homeless. Using this water harvesting techniques will increase the farmer's productive capacity under a combination of excessive demographic pressure and unsustainable agricultural

practices in the valley areas prone to flooding.

In addition to adopting field water harvesting techniques, Irrigation practices should be introduced to allow farming activities during the dry season period. It is very disheartening to note that the northern part of the country is mostly affected where rainfall is less than 4.5 months in a year and where most of our cereal crops are grown.
Manning roughness coefficients (n) for the various types of soils surfaces identified and developed, can be adopted as a design parameter for various types of construction works within the irrigation farm site instead of looking for a table developed elsewhere. Finally, it has been shown that this model provides improved understanding of the hydrologic and hydraulic processes that are most important to the local farmers and structural engineers in Nigeria.

An Integrated Water Resources Management (IWRM) should therefore be pursued to ensure sustainability. It is also advised that radical water demand management be applied. Efforts to discourage uneconomical use of water resources be aggressively pursued through sensitization and advocacy.

5.0 ACKNOWLEDGMENTS

Mr. Vice Chancellor, Sir, and Distinguished Members of the audience, I would like to acknowledge some of the notable individuals and corporate bodies who have made significant contributions to the success stories of my life and made unique impact in the course of my academic career. To save time, I shall specifically mention a few names, but pardon me if I did not mention your name, it is not deliberate.

Let me start by giving Honour and Glory to the Almighty God for sparing my life, for His love, Grace, Favour and inspiration for sustaining me to this professional height and for granting me this

rare opportunity to deliver this Inaugural Lecture. I say "Thank you JESUS".

I sincerely appreciate and give special thanks to my late parents, Chief Olowa of Ilemo, J.B. Adewumi and Mrs Maria Folake for their love, parental and Godly care, labour, Kindness, prayers and deep investment towards my academic and professional development.

I would like to pay some tributes to members of my extended family – brothers, sisters and cousins for their moral, financial and spiritual supports. – Justice J.F. Gbadeyan (Rtd) Mr Folorunsho Alayande (late), Mr. Segun Awe (UK), Mr. and Mrs Julius Sunday Babalola, (Mr. & Mrs Olusola Oladele Osasona – childhood friend UK), Mr & Mrs Elisha Oladele Aina, Pastor & Mrs Michael Olayemi – cousin, Elder & Mrs Oluranti Idowu – cousin, Mr Biodun Adewumi, Oladele Adewumi, Olusoga Adewumi, Mrs Bunmi Adewumi, Mr Sesan Adewumi, Mr Sunday Adewumi, Mrs Iyabo Obamuyiwa, Capt.(Rtd) Bamidele, Mr.& Mrs Yemi Ajayi, Mrs Folakemi Adeosun (Nee Adewumi) -Permanent Secretary) Mr. Dele Omotoyinbo, Mr Olu Omotoyinbo, Ms Florence Babalola (late), Mr Femi Olayemi, Mr & Mrs Sunday Ajayi, Mr & Mrs Yemi Aina, Mr. Salau Raji, Hon. Ezekiel Folarinde Gbadeyan, Mrs Felicia Idowu, Pastor & Mrs. Adeoti, Hon. Sam Bamisaiye, Mrs Funke Kolapo, Mrs Oluwajumi Abidoye, Dr Niyi Olatunji, Bros Niyi Fadumila, Prince Adeyeye Fagbemi, Mr. Olufemi Olatunji, Femi Adeojo, Engr & Mrs Wole Oke, Mr. & Mrs Adu, Mr. & Mrs Nwaha, Mr Joshua Adio, Mrs Toyin Oke, Mr & Mrs Femi Babalola (USA), Mr. & Mrs Alice Adejare, Mr. & Mrs Sarah Fadesere.

Sepia Club – Obbo-Aiyegunle:

Chief Magistrate Fabunmi Dada (Rtd), Senior Apostle J.F. Afolabi, Senior Apostle J. Ade Dada, David Dr. S.A. Adeniyi, Mr. M.O. Adeyemi, Mr. S.A. Agbana (late), Mr. Shola Ogunjide, Engr. S. Jide Ogun, Chief Hon. F. Gbadeyan, Elder Oluranti Idowu, Mr. G.A. Agbana (late), Mr. E.O. Abegunde, Engr. W.O. Oluwaseyi, Dr. S.A. Faseyi (Late), Mr. Ade Ogunkunle, Dr. S.B. Faseluka, (late), Dr. Shola Ogun, Mr. S.J. Daramola, Mr. Ade Ajayi, Arch. E.A. Ogun, Deacon J.A. Olurotimi, Mr. I.W. Ogun, Mr. Sunday Ajayi, Mr. Dele Fatoye, Prof. Samuel Femi Ajayi, Mr. Olu Ajayi, Elder Olu Ogunmola, Mr. Segun Fatigun (Late).

All my mate Old Students Association (IBGS) of 75 set, Mr. & Mrs A.A. Morounfola (Late) – My Principal at IBGS, Igbaja, Particularly National Chairman Engr Segun Olatunji and the National Secretary – Mr Timothy Ajala.. Ganiyu Ibrahim, Mr Lanre Olarewaju, David Shola Alu, Dolapo El-Mashood, Silifat Jimoh, Prof. Ganiyu Abdulrahman (Ghana), Mr Biodun Badmus (UK)

From Ahmadu Bello University – Prof. A.A. Ramalan (late), Prof. O.J. Mudiare, Prof. M.A. Oyebode, Prof. A. El-Okene, Prof. Suleimam Maiwada, Prof. Henry Igbadun, Prof. Dumoye, Prof. Oyedipe, Prof. C.A. Okuofu (late), Prof, Johnson Otun, Prof, B.D. Adie, Surveyor Sam Faggason (Late), Prof. Ghaji, Prof. S.M. Misari (Late), Prof. Echekwu, Prof. Joshua Ogunwole (Former Bowen University VC), Prof. S.Z. Abubakar (VC, Capital City University, Kano), Prof. L.G. Abubakar, Prof. Itodo (VC UniAgric, Makurdi), Prof. Kucha former VC UniAgric Makurdi,,Prof. O.B. Oloche, Dr O.A Bamgboye – Former ExecutiveDirector NWRI, Kaduna, Prof. & Mrs Francis Showemimo, Prof. Balogun, Prof. S.T.O Lagoke, Prof. D.D. Yusuf, Prof. U.S. Mohammed, Prof. Moshud Isiaka, All the secretariat staff in the Department of Agricultural Engineering, ABU, Zaria, All the Workshop staff – Mr. Ayo Asala, Mr. Femi

Odofin, Mr. Ezekiel Maigari, Pastor E.J. Ayeni (Rtd), Mr. Oladimeji (Rtd), Mr. Adebija (Rtd), Engr. M.K. Dalhat, Engr. Ayo Badmus (Bow-tie), Mr. & Mrs S.B. Adeyi, Mr. Jimmy Folaranmi (Uncle J), Prof. J. Osinubi (ABU), Prof. S.P. Ejeh, Prof. Tony Okpe, Prof. Sony Oniye, Prof. M.K. Othman, Prof. Amartey, Prof. Muazu, Prof. Adegboye

My immediate community – Chairman CDA-Mr Elemide, Mrs Obembe, Pst Adeleke Faith Baptist Church, Mr.& Mrs Adegbite, Alhaji Adedayo, Mr. Sojobi Past CDA Chair, Mr.& (Dr) Mrs Daniel Ologe, Dr & Mrs Ajayi, Mr. Fatokun, Dr (Mrs) Grace Adamu, Mrs Banarbas, Engr & Dr Mrs Oladele, Mr. & Mrs Adebayo, Oba Taidob College, Arch. Anasanwo, Pst & Mrs Sonde, Alhaji Majolagbe and other members of executive.

All College of Engineering Academic and Non-Academic staff – Prof, O.U. Dairo (Dean), Prof Adetunji Deputy Dean, Prof. O.A. Adebisi (Late), Prof. Peter Aiyedun -Past Dean of Engineering), Prof. E.S.A. Ajisegiri -Past Dean, COLENG), Prof. Adejuyigbe (Late) – Past Dean, COLENG), Prof G.A. Adegboyega (inception Dean, COLENG), Prof. B.A. Adewumi, Prof.& Mrs Awokola, Prof.& Mrs A.F. Adisa Prof. Waheed, Prof. Ismaila - Former Dean), Prof. TMA. Olayanju – immediate past Landmark University VC), Prof Mrs Kuye, Prof. O.J. Akinyele, Dr. A.C. Ukatu (Late), Dr. G.A. Bolaji (Late), Dr O.S. Olokode (Late), Engr S.G. Oyagbiring, Prof. Aderinlewo, Prof. A.A. Adekunle- Fed. University, Otuoke, Prof. L.O Kehinde, Engr. Mrs I.B. Oronti, Mrs F.O. Durodola, Dr Mrs Funmilayo Alayaki, Dr. O.S. Abiola, Dr Ola, I.A. (HOD, ABE), Dr S.O. Odunfa (HOD, CVE), Dr Amusa (HOD, EEE), Dr Adekunle (HOD,MCE), Prof. G.A. Adepoju (HOD,MTE), Prof. O.T. Olateju, Dr. Gbenga, Omotainse, Dr U.T. Tobit, Assoc. Prof. A. Badejo, Assoc. Prof. O.J. Adeosun, Assoc. Prof.. A Sobowale – National Chair, NIWE, Assoc. Prof. Dada, P.O.O. Engr. Fidelis

Nkeshita, Engr Victor Adepoju, Dr. A.O. Akinola, Dr. Ben Anyanwu, Dr A.T. Oyelami, Engr. A.A. Ishola, Engr S.O. Owoeye, Engr. A. Olaoluwa, Mr. Sonde, Mr. Rasheed Ojelade (Owonikoko), Mr. Ayinde Adewale, Mr. Popoola, Mr. Oyekunle, Mr. Razak Mukaila, Mr. Olukan Noah, Mr. Ayinde Adewale, Mr. Adeniyi, Engr. Oluwatudimu, Engr. P.O. Adetiloye, Surv. O.T. Okunola, Mr. C.A. Cosmos, Mrs G.A. Adewumi, Engr. Mrs Arominiyi Mosunmola Veronica, Mr Emele, Mr. I.O. Ajisegiri, Mr. N.A. Amusa, Miss O.O. Makinde, Mrs Olatunbosun, J.O., Mr. Omodunbi M.J.,

My special thanks goes to all the staff that work under me as the Dean of Engineering – Mr Jacob Soremi, Mr Abare, Mr Idowu, Mrs Sonde (Sec to the Dean), Mr. Richard Abiola, Mrs Aina, Mrs Adeosun, Rev. Mrs Adeyemo, Mrs Enikuomehin, Alhaji. Ewedairo, Mr. Odunjo, Mrs Sumaila, Pst Mrs Akinpelu, Mrs Olayinka (present Dean Secretary), Mr and Mrs Jolaoso, Mrs Aina, Mr & Mrs William, Mrs Eyiowuawi (HOD Sec), Mrs Oladipupo, Mrs Olabode Kehinde (Sec MCE), Mrs Adewolu Kuburat (Sec EEE), Mrs Awoyale, T.B., Mrs Ogunsanya Omotunde Khadijat Abimbola, Mrs Bilewu Titilayo O.

Prof. & Prof Mrs Goke Bodunde, Prof (late)& Prof Mrs Phillips, Prof & Mrs Omotayo, Prof & Mrs O.A. Enikuomehin (Former Ag. VC), Prof. & Mrs Takeet, Prof. Ikeobi (DVC), Prof. Agboola (Rtd), Prof. & Mrs Attungwu, All Deans and Directors, Prof. Talabi, Prof. Omotainse (late- Former Dean Colvet), Prof. & Prof Mrs Dipeolu. Prof.& Mrs Fakoya, Prof Mrs Sotiloye, Prof. Akeredolu-Ale – Former DVC), Prof & Prof Mrs Onifade, Prof. Mrs Babalola, Prof. Samuel Awonorin (Late) Engr Opeodu Francis, Prof. & Mrs Atayese, Prof. J.K. Adesodun, Prof. Alegbeleye, Prof. Adeofun, Prof & Prof Mrs Lateef Sanni, Dr. & Prof Mrs Adegbite, Prof. & Mrs Olaoye, All the staff of AMREC, Prof & Prof Mrs Oluwalana, Prof. & Dr Mrs Makinde, Prof. &

Mrs Badmus, Engr. & Prof Mrs Okeyode, Prof & Mrs Mustapha, Prof Mrs Alaba Jolaoso Prof. E.U.Nwa (Rtd), Prof. & Mrs Duru (Rtd), Engr. R.C. Yadav (Rtd),
Prof. O Olufayo, Prof. Phillip G. Oguntunde, Prof. Omofunmi, Prof. Alabadan, Prof Fasinmirin, Prof. Olukunle, Prof. B.A. Raji, Prof, Suleiman Salami, Prof. Ogunlela, Prof. Ejieji, Prof. K.C. Oni (Rtd), Prof, Ganiyu Abdulraman (Ghana), Prof. Sadiq (Unilag), Prof. Joseph Afolayan (Former Anchor University, VC), Engr & Mrs. Tunji Kadri, Engr & Mrs Elijah Adeniran, Engr & Mrs Peter Ogunbiyi, Prof. & Mrs A.Y. Sangodoyin (UI), Prof Manuwa, Prof, Leo Agbetoye, Dr. O.O. Olarewaju, Prof. Babatola, Prof. Owolabi, Prof. J. O. Akinyemi (OOU), Dr. Akinyemi (OOU), Engr. Ayo Babalola, Dr Samuel (OOU), Engr. Sosanya,

In-Laws – Mrs Obe (mother in-law), Mrs Olufolake Odegbami, Mr & Mrs Johnson Kolawole Idowu, Mr. & Mrs (Nee Adewumi) Dipo Obe, Brig. (Rtd) & A. Olajide, Mrs Tayo Fayomi, Mrs Taiye Ogun, KC Afolabi (FRSC), Femi Afolabi (NCDC), Mrs Ope, Mr. Afolabi (Zaria), Mrs Afolabi (Zaria), Most Senior Apostle Afolabi, Femi Bamidele, Busayo Bamidele, Gbenga Bamidele, Hendrix Bamidele, Mrs Mope Mrs Moni, Mr.& Mrs Shola Olajide, Mr. Faseyi, Lawyer Ope Aina,

My RCCG Pastors: Pst & Mrs Tejuoso, Pst & Mrs Julius Adeyemi, Pst & Mrs Dapo Oyegunle, Pst & Mrs Faith Adewole, Pst & Mrs Ayoola Paul, Pst & Mrs Abel Olusegun, Pst & Mrs Olubanwo Lanre, Pst & Mrs Oyero Augustin, Pst & Mrs Oyelami Stephen, Pst & Mrs Esue Stephen. Pst& Mrs P.O.O. Dada,
RCCG ELDERS APAPAOYO4 (Ibadan): Elder Dr. Olarewaju (Chairman), Capt Olusesan (Rtd), Folasade Fasina (Rtd), Pst Olajumoke, Col. Adeyemi Gbenga (Rtd), Elder Kolawole, Elder Segun Benson, Elder Oladotun, Mrs Abijo, Mrs Elder Regina Olubunmi, Mrs kopji, Pst Mrs Oluwatuyi Esther, etc.

6.0 REFERENCES:

Abubakar, S.Z., M.K. Othman, O.J. Mudiare and **J.K. Adewumi**.(2001). Hydraulic Functioning of Main System of Hadejia-Valley-Irrigation-Project and Effective user Participation in Operation and Operation and Maintenance.*Savanna Journal of Agricultural Mechanization.* 3. (1): 19-23.

Adewumi J.K. and Duru, J.O (1984).Consumptive use Coefficients for selected crops in Samaru, Northern Nigeria.*Nigerian Journal of Engineering.*II(1): 1-8

Adewumi, J.K. (2000). Soil Loss Tolerance limit for Effective Conservation Measure in Samaru, Northern Nigeria.*Savanna Journal of Agricultural Mechanization*. 2 (1):23-27

Adewumi, J.K. (2001). Soil detachment by raindrop impact: Comparision of Predictive Models. *Savanna Journal of Agricultural Mechanization.* 3 (1): 25-30 ISSN: 1-596-153-2

Adewumi, J.K., O.J. Mudiare, J.J. Owonubi. (2001). Soil Erosion Prediction in Samaru-Zaria: Comparision of two predictive models. *Savanna Journal of Agricultural Mechanization*. 3 (1):9-13ISSN: 1-596-153-2,

Adewumi, J.K. and A. Kolawole.(2002). Water harvesting for dry land farming.*ZARIA GEOGRAPHER.Journal of Environmental Studies and Human Development. New Series*. 15 (1): 24-33. ISSN: 0795-7599.

dewumi, J.K., Sobowale, A. and Kolawole, A. (2015). Influence of water harvesting on Farmer's productivity in Semi-Arid areas of Nigeria. *Journal of Agricultural Science and Technology A.* 5(1): 8-14.Serial No 43.

Adewumi, J.K. J.J. Musa, O.J. Adeosun, Otuaro Ebierin Akpoebidimiyen, A. Adekunle, Babafemi, Sunday Adewumi

(2020).Soil detachment with Organic Mulching using Rainfall Simulator in comparison with a short duration Natural Rainfall for effective soil conservation.*Journal of Environmental Protection.* **11**, 457-469. doi: 10.4236/jep.2020.116027.

Brady, N.C., R.R. Weil (2008). The Nature and Properties of Soils, 14th ed., Pearson Education, Inc., New Jersey, USA, 2008, p. 965.

Dexter AR 2004. Soil physical quality: Part I. Theory, effects of soil texture, density and organic matter and effects on root growth. Geoderma, 120(3-4): 201-214

Egharevba, N.A., O.J. Mudiare and **J.K. Adewumi** (2005). Crop Coefficient of Corn (zea mays) as influenced by water table depths under green house culture, *Nigerian Journal of Engineering.* 12.(2):54 – 59.

Food and Agricultural Organization. 2002. "Food Insecurity: When People Must Live with Hunger and Fear Starvation." In The State of Food Insecurity in the World (SOFI), 4th ed., Rome, Italy: FAO, 355.

Gijsman A.J., S.S. Jagtap, J.W. Jones, Wading through a swamp of confusion: How to choose a method for estimating soil water retention parameters for crop models, *Eur. J. Agron.* 18 (2): 75-105.

Koudahe, K., Koffi, D.,**Kayode Johnson Adewumi**, Awokola, S.O. and Adebola,

A.A. (2018).Impact of Climate Variability on Crop Yields in Southern Togo. Environment Pollution and Climate Change , an *Open access Journal*. 2 (1):1-9.

Komlan Koudahe, Koffi Djaman and **Johnson K. Adewumi** (2018). Evaluation of the Penman Monteith reference evapotranspiration under limited data and its sensitivity to key climatic variables under humid and semiarid conditions. *Modelling Earth.Systems and Environment*. 4 (3): 1239 – 1257. ISSN 2363-6203

Komlan Koudahe, ***Adewumi, J.K***., Awokola, O.S., Adekunle A. A. (2017). Trend Analysis in Standard Precipitation Index and Standardized Anomaly Index in the Context of Climate Change in Southern Togo.*Atmospheric and Climate Sciences*.7: 401 – 423.

A.L.E. Mofoke, **J.K. Adewumi**, F.E. Babatunde, O. J. Mudiare, A.A. Ramalan (2006). Yield of Tomato grown under continuous-flow drip irrigation in Bauchi state of Nigeria. *Agricultural Water management*84 : 166 – 172. UK: www.elsevier.com/locate/agwat

Mofoke, A.L.E., **J.K. Adewumi,** O.J. Mudiare and A.A. Ramalan (2004). Design Construction and Evaluation of An Affordable Continuous – flow Drip Irrigation System". *Journal of Applied Irrigation Science,* Germany. 39 (2): 253 – 269. ISSN 0049 – 8602.

Musa, J. J., Ode, O. G., Anijiofor, S. C. and **Adewumi J. K.** (2011): Quality evaluation of household wastewater for irrigation. *J. Applied Sc. Environment Management.* 15(3): 431-437

Musa, J. J., **Adewumi, J. K**., Bolagi, G. A. and Ohu, J. (2011): Seasonal effects of infiltration rates of some selected soil types in North Central Area of Nigeria. *J. of Biodivesity and Bological Sciences*.1 (4): 342 – 351. ISSN: 2008-9287. Fall 2011 JBES. info@jbes.ir

Musa, J. J., **Adewumi, J. K.** and Ohu, J. (2012): Comparing developed Manning coefficients for some selected soils in Gidan Kwanu with existing values. *The Electronic J. of Geotechnical*

Engineering (EJGE) 17(3): 2999-3008
Musa, J. J., **Adewumi, J. K**. and Ohu, J. (2013): Comparing developed runoff coefficients for some selected soils in Gidan Kwanu with existing values. *International J. of Basics and Applied Sciences.Insan Akademika Publications.* 1 (3): 473-469.

Musa, J.J., ***Ode, O. G; Anijofor, SC and Adewumi, JK.(2011).*** *"Quality Evaluation of Household wastewater for irrigation".Journal of Applied Sciences & Environmental Management (JASEM), 15(3): 431 – 437*

Musa, J.J., **J.K. Adewumi,** P.O.O. Dada, I.A. Kuti, A.S. Mohammed and T.N. Eze (2018). 'Determination of Soil Erodibility Indices for Selected Soils in Southern Guinea Savanna Ecological Zone of Nigeria Under Rainfed Agricultural Practice'. *FUW Trends in Science & Technology Journal.*www.ftstjournal.com. 3(2): 652-657 e-ISSN: 24085162, p-ISSN: 20485170

Musa, J.J., E. A. Otuaro, Pius O. Dada, **J.K. Adewumi**, I.A. Kuti and Jamil Adams-Suberu (2021). Validation of Universal Soil Loss equation for selected Soil Locations in North Central Nigeria using a rainfall Simulator. AgricEngInt: *CIGR Journal Open Access* @ http://www.cigrjournal.org 23 (3): 21-30

Odunze, A. C., K. B. Adeoye, J. J. Owonubi, ***J. K. Adewumi,*** *V. O. Chude and E. N. O. Iwuafor (1997). Rainfall Characteristics and soil tillage timing for Rain fed crop production in the Northern Savanna of Nigeria.* ***ITC Journal*** *(1997 – 3/4), Geo-information for Sustainable Land Management (SLM), Pp 59 – 65.*
Oladipo, I.O., ***Adewumi, J.K.***, Dairo, O.U., Adejuyigbe, S.B. and Ajayi, E.A. (2013): Performance Evaluation of Dry Season Okra under Sawdust and Trash Mulch Cover Treatments in Southwestern Nigeria. *Open Journal of Soil Science*. 3:337-341.www.scirp.org/journal/ojss

Oladipo, I.O. and **J.K. Adewumi** (2013). Computer Aided Drip Irrigation Design for Nigerian Agricultural Environment. Open Access Scientific Reports. 2: 638. Doi:10.4172/scientificreports.638. 2 (2): 1-4

Otun, J.A. and **Adewumi, J.K.** (2010). Analysis Of Dry Spells And Its Application To Crop Planning In The Sudano-Sahelian Region Of Nigeria. *Arid Zone Journal of Engineering, Technology and Environment.* 7: 34 – 43.

Otun, J.A. and **J.K. Adewumi**. (2009). Drought quantification in semi-arid regions using precipitation effectiveness variables: in 18th World IMACS/MODSIM Congress, Cairns, Australia. 13-17 July, 2009. pp. 3266-3272. www.mssan.org.au&www.research.rutgers.edu/-imacs/ .

Sobowale, A., **Adewumi, J. K**., Otun, J. A. and Adie, D. B. (2010): Water resources potentials of Hadejia River sub-catchment of KomaduguYobe Rover Basin in Nigeria. Agric Engineering *Internatial CIGR Journal*.12(2): 1-6. .

Sobowale, A., **J. K. Adewumi**., Bamigboye, O. A. and Awokola, O. S. (2011): Capacity building network approach to IWRM implementation in Southwestern Nigeria. *International Conference on Integrated Water Resources Management* 12th-13th Oct. 2011, Dresden Germany.

Sobowale, A., **J. K. Adewumi.**, Bamigboye, O. A., Awokola, O. S., Bashir, D. and Egbulem, A. N. (2011):Towards water resources management in South Western Nigeria: The role of Capacity Biulding Institutions (CBIS). *Proceedings of 2nd National Water Resources and Sanitation Conference Kaduna Nigeria.*203-211

Sobowale, A., ***J.K. Adewumi,*** *Otun, J.A. and Adie, D.B. (2008) Water Resources Management of* ***Jamaare and Misau Rivers***

Sub-Catchment *of Komadugu Yobe River Basin, Nigeria. Nigerian Journal of Engineering, Ahmadu Bello University, Zaria 14 (2):54 - 59*

Sobowale, A., **J. K. Adewumi.**, Bamigboye, O. A. and Awokola, O. S. (2011): Capacity building network approach to IWRM implementation in Southwestern Nigeria. *International Conference on Integrated Water Resources Management* 12th-13th Oct. 2011, Dresden Germany. United Nations World Water Development Report 4. UNESCO, UN-Water, WWAP. March 2012. World Population Prospects: The 2008 Revision, Highlights. UNDESA. 2009. World Agriculture: Towards 2030/2050 – Interim Report – Prospects for Food, Nutrition, Agriculture and Major Commodity Groups. FAO. 2006.

University Senate Building

ISBN: 789-789-799-090-2