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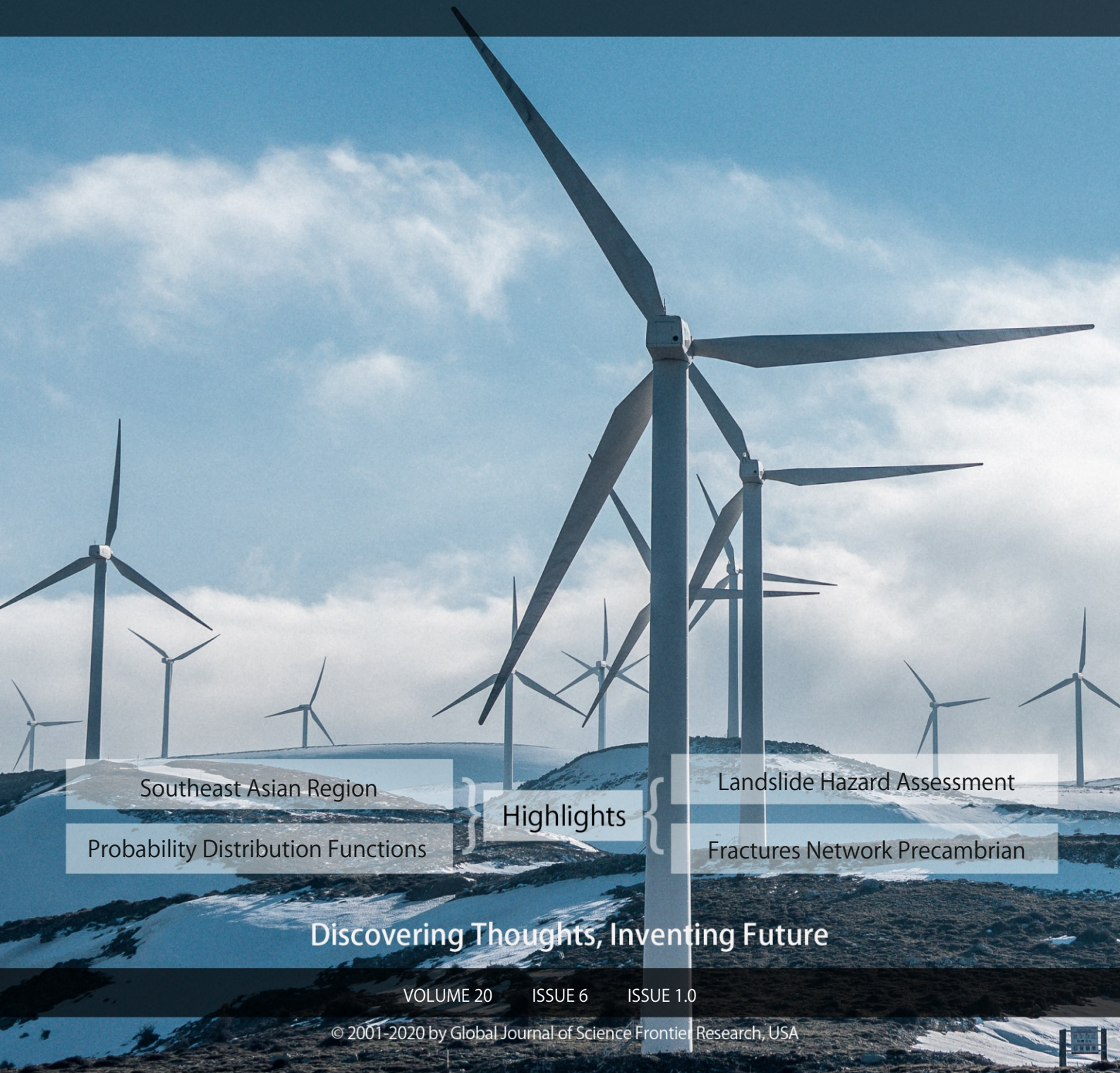

Highlights

Southeast Asian Region

Probability Distribution Functions

Landslide Hazard Assessment

Fractures Network Precambrian

Discovering Thoughts, Inventing Future

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Climate Change, South Asia and Southeast Asian Region

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Abstract- It is well known that the climatic conditions of our earth have changed since its origin. In its early days environmental conditions were not suitable for life. However, with due course of time it has changed and origin of life took place. Scientists have found seven cycles of glacial advance and retreat during the last 650,000 years and also that the last ice age abruptly ended about 7,000 years ago. The phenomenon of climate change has many implications and immense effects on our environment. There are many factors such as emissions of greenhouse gases, deforestation, urbanization and industrialization which impact the climate. Some of the major consequences of climate change include impacts on sea level rise in coastal areas, impacts on forestry, agriculture and food productivity, life and property in coastal areas, marine life, wildlife habitat and natural ecosystem, biodiversity, glaciers, floods and human health. This paper is an attempt to understand the phenomenon of climate change, historical evidences of climate change, identify reasons of global warming and climate change and its consequences in the South Asia and, in its neighbouring regions.

Keywords: *climate change, global warming, impacts, south asia.*

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I. Introduction

The entire South Asian region is one of the most densely populated regions in the world with very diverse climatic conditions. This region is also one of the most exposed and vulnerable regions in terms of the threats of experiencing major climate change. A considerable section of the South Asian population is heavily dependent on agriculture for their livelihood and they have to bear the consequences of the changing climate. The human population of South Asian region is estimated to increase up to 2.2 billion by 2050, from the current population of about 1.5 billion. It has been estimated that nearly 600 million South Asian population belong to a very low income group, that means even a small impact of climatic change can cause irreversible damage pushing a large number of poor people into destitution. As per the World Bank report, the South Asian region has experienced significantly longer summers and in some cases severe heat waves, over the years. In recent times, the frequency of more intense rainfall has increased-leading to severe floods in low lying areas, landslides in hilly regions and debris flow in many parts of the region. At the same time, the total amount of precipitation has declined in the region.

The main factor responsible for climate change over certain time period, is due to increase in the concentration of carbon dioxide (CO_2) gas and other global warming gases in the atmosphere. The increase in the concentration of CO_2 and other Greenhouse gases (GHGs) has been caused due to increase in economic and other industrial activities, such as energy, industry, transport, and land use changes, many of which rely heavily upon burning of fossil fuels. The most important GHG is carbon dioxide (CO_2) that currently constitutes near about 77 per cent of the global warming potential. Another important contributors of global warming include emission of methane (from agricultural sources), and land use change such as deforestation. The concentration level of GHGs has increased due to the fact that emissions during the last two centuries were in excess of what could be naturally absorbed by the atmosphere, resulting in excess GHGs that began to accumulate in the atmosphere. The concentration level of CO_2 alone has increased by nearly 100 ppm over this period (Stern, 2006). The current level of global emissions contributes another 2-3 ppm of carbon dioxide equivalent (CO_2) GHGs per annum.

What is climate change?

The climate of any region is the sum total (average) weather conditions of that geographical area. It includes rainfall, temperature variation, humidity and wind. The climate of any region is affected and influenced by many factors such as topography of the region, longitude, latitude, the tilt of the Earth's axis, proximity to the coastal areas, the movements of the wind belts and temperature differences between land and sea in the coastal areas. The term 'climate change' is synonymously used as 'global warming' and it refers to the rise in average temperatures on the Earth's surface. The term 'global warning' is generally used to describe a gradual increase in the average temperature of the Earth's atmosphere, oceans and is significant enough to permanently change the global climate.

The climate change is a multi-dimensional phenomenon and is affected by many factors in long time period. While many people consider the effects of global warming to be more rapid and more substantial than others do. The scientific consensus on climate changes related to global warming is that the average

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global temperature of the Earth has risen somewhere between 0.4 to 0.8°C during the last 100 years. Majority of the scientific community agrees that global climate change is primarily taking place due to the excessive burning of fossil fuels, which causes emission of carbon dioxide and other greenhouse gases (GHGs) into the atmosphere. The increased volume of CO_2 and other greenhouse gases (GHGs) released by combustion of fossil fuels such as petroleum oil and coal, forest land clearing, agricultural activities and other human activities are believed to be the main sources of global warming that has occurred over the past 50 years.

The greenhouse gases have the capacity to trap solar heat energy within the atmosphere, which can have many adverse effects on our natural ecosystems, agriculture sector and human health. The climatic changes resulting due to the global warming may lead to the rise in sea levels in the coastal areas due to melting of the mountainous glaciers and polar ice caps, as well as an increase in occurrence and severity of floods, droughts, cyclones, typhoons, storms and other severe weather events.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) dispelled many uncertainties about climate change. The IPCC Report (2007) gave detailed projections for the 21st century and these projections showed that the trend of global warming will continue further and may accelerate in future. Scientists associated with the Intergovernmental Panel on Climate Change (IPCC) carrying out researches on global warming have predicted that average global temperature could increase somewhere between 1.4°C and 5.8°C by the year 2100. It has also been estimated that even if developed and developing countries make efforts to reduce their greenhouse gas emissions, the Earth will continue to warm further under the influence of climate change.

The debate over climate change

Many social activists advocating issues of climate change, politicians and scientists working on various aspects of climate change have diversified opinions and differ in their view points. They often debate within, between and among many other communities/people, sometimes even on the radio programmes, TV news channels and other platforms with regard to the problem of climate change- whether the climate change or global warming is real. Some of them opine and call it a hoax or hype to benefit a few select stakeholders. However, within the scientific community across the nations, there is broad-based consensus and agreement that the phenomenon of climate change is real. Most of the researchers and scientists doing research on climate change and engaged in analyzing the available data and facts agree that the planet Earth is gradually warming. Many ogranisations such as the U.S. Environmental Protection Agency, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration and other scientific agencies/organizations doing scientific research and working on climate change agrees that climate change is indeed occurring and is almost certainly due to the increased emissions of CO_2 and other greenhouse gases (GHGs) from various anthropogenic activities.

It is very interesting to see that while consensus among all the researchers, scientists, scientific organizations, and government agencies is that climate change is actually happening. It is also agreed that the global warming is mainly caused by industrial gaseous emissions and other human activities. There are certain organizations, pressure groups and individuals, although small in number, are questioning the validity of such assertions and prefer to cast doubt on the occurrence of evidences on climate change. Those who argue against the problems of climate change or global warming often claims that recent changes in climate can be mainly attributed to human activities and can be seen as a part of the natural variations in the Earth's climate and temperature. They also argue that it is extremely difficult or almost impossible to establish a direct relationship between climate change and any single weather event, such as a floods, typhoon or hurricane. While the latter is generally true, however decades of climate data analysis supports the reality of climate change and the role of human factor in this process. In any case, economists generally agree that initiatives and preventive measures taken to reduce or minimize industrial and fossil fuel emissions would be far less expensive than dealing with the consequences of not doing so.

Evidences of Climate change

There is no doubt that the climate has changed throughout the Earth's history since the formation of our planet. Based on the evidences, scientists have found that during the last 650,000 years there have been seven cycles of glacial advance and retreat. They have also found that the last ice age abruptly came to an end about 7,000 years ago. The sudden and abrupt end of the ice age also marked the beginning of the modern climatic era and of human civilization. Most of these climate changes are attributed to very small variations in Earth's orbit that change the amount of solar energy our planet receives.

The detailed scientific researches on climatic events during the past 150 years have revealed that the average atmospheric temperature has risen all over the globe. It has also been observed that the global warming has occurred in two distinct phases- the first phase has been estimated to be from 1919 to 1940, with an average temperature gain of about 0.35°C. The second phase of global warming has been estimated to

be from 1970 to the present, exhibiting temperature gains of about 0.55°C. The oceans water has absorbed much of this increased heat, with the top 700 meters (about 2,300 feet depth) of ocean water showing warming of nearly 0.302 degrees Fahrenheit since 1969. The records of climate change also show that the last 25-30 years have been the warmest time of the past five centuries. The global warming has caused the rise in average temperature of the oceans, rising of the sea levels, melting of ice glaciers, and diminishing of snow cover in the Northern and Southern Hemisphere. Observations by remote sensing satellites also reveal that the amount of spring snow cover in the Northern Hemisphere has decreased over the past five decades and that the snow is melting earlier. The current warming trend is of particular significance because most of it is extremely likely (greater than 95 percent probability) to be the result of anthropogenic activities since the mid-20th century and proceeding at a faster rate that is unprecedented over decades to millennia.

The earth-orbiting remote sensing satellites and other technological advances have enabled scientists to see the larger picture, facilitating collection of many different types of scientific data, information and its analysis about our planet and its climate on a global scale. This large volume of data and information collected over many years has clearly revealed the signals of a changing global climate.

The heat-trapping properties of carbon dioxide and other such greenhouse gases were demonstrated in the mid-19th century. Their property to affect the transfer of infrared energy through the atmosphere is the scientific basis of many instruments flown by NASA. There is no doubt that the increased concentration of greenhouse gases has led to the warming of the Earth's atmosphere in response.

Ancient evidences related to climate change can also be found in tree rings, ocean sediments, coral reefs, and layers of sedimentary rocks. This ancient or paleo-climate evidences reveals that current rate of global warming is occurring roughly ten times faster than the average rate of ice-age-recovery warming. The scientific analysis of ice cores drawn from Greenland, Antarctica and mountain glaciers in tropical regions shows that the Earth's climate responds to atmospheric changes in levels of greenhouse gases.

The scientific studies in recent times suggest that during the last century, the global sea level has risen to about 8 inches. It has also been observed that the rate in the last two decades, however, has nearly double as compared to the last century.

The scientific researches also reveals that the Earth's average surface temperature has risen to nearly 2.0 degrees Fahrenheit (1.1 degrees Celsius) since the late 19th century, which is largely driven by the increased levels of carbon dioxide and emissions of other GHGs into the atmosphere. These studies further suggest that most of the global warming has occurred during the past 35 years, with 16 of the 17 warmest years on record occurring since 2001. The year 2016 was not only the warmest year on record, but eight of the 12 months that make up the year from January through September, with the exception of June, were the warmest on record for those respective months.

It has also been observed that the mass of ice sheets in Greenland and Antarctic have decreased in recent times. Scientific data from NASA's Gravity Recovery and Climate Experiment show that Greenland has lost nearly 150 to 250 cubic kilometers (36 to 60 cubic miles) of ice per year between 2002 and 2006, while Antarctica has lost about 152 cubic kilometers (36 cubic miles) of ice between 2002 and 2005. Over the last several decades, both the extent and thickness of Arctic sea ice has rapidly declined.

There are various studies showing that mountain glaciers are retreating almost everywhere around the world, including glaciers in the Africa, Andes, Rockies, Alaska, Alps and Himalayan mountain ranges.

It has been noticed that the United States has witnessed increasing numbers of intense rainfall events in the last six decade. It has also been observed that since 1950s, the number of record high temperature events in the United States has been increasing, while the number of record low temperature events has been decreasing.

The acidity of surface ocean waters has increased by nearly 30 percent since the beginning of the Industrial Revolution, which is the result of anthropogenic emission of more carbon dioxide into the atmosphere and hence more being absorbed into the oceans. The amount of carbon dioxide absorbed by the upper layer of the oceans is increasing by about 2 billion tons per year.

What are the causes of climate change?

The burning of fossil fuels, such as petroleum oil and coal, which emits greenhouse gases into the atmosphere, mainly carbon dioxide are considered as the primary causes of climate change. Other anthropogenic activities such as burning of agriculture residue and deforestation also contribute to the increased concentration of greenhouse gases that causes climate change.

As suggested by various scientific studies, it is now clear that climate change related to global warming is mostly happening due to increased emissions of greenhouse gases (mostly CO_2). Over the last century, atmospheric concentrations of carbon dioxide has increased from a pre- industrial value of about 278 parts per million (ppm) to nearly 379 parts per million (ppm) in the year 2005. During the same period, the average global temperature rose by about 0.74° C. According to scientists, this is the largest and fastest warming trend in the history of the Earth that they have been able to

discern. The World Meteorological Organisation (WMO) Greenhouse Gas Bulletin showed that globally averaged concentrations of carbon dioxide (CO_2) reached 407.8 parts per million in 2018, up from 405.5 parts per million (ppm) in 2017.

The increase in CO_2 from 2017 to 2018 was very close to that observed from 2016 to 2017 and just above the average over the last decade. Global levels of CO_2 crossed the symbolic and significant 400 parts per million benchmark in 2015.

Some quantities of these global warming gases are naturally occurring and are critical part of Earth's temperature control system. It is significant to notice that the atmospheric concentration of CO_2 did never rise above 300 parts per million (ppm) between the advent of human civilization roughly 10,000 years ago and 1900. But in recent times, it's concentration in the atmosphere has reached to about 400 parts per million (ppm), a level never reached in more than 400,000 years in the Earth's history and is the main cause of global warming.

It has been observed that an increasing rate of global warming has particularly taken place over the last 25-30 years. It has also been observed that 11 of the 12 warmest years on record have occurred during the past 12 years.

II. Consequences of Climate Change

It has been estimated that the South Asia and Southeast Asian countries will be among the regions hardest hit by the consequences of climate change. Countries like Bangladesh, India, Vietnam and Sri Lanka in particular, will feel the impacts of climate change acutely due to large coastline. Climate change resulting due to rising temperatures is expected to cause more extreme weather events, rising sea levels, increasing cyclonic activity in the Bay of Bengal and the Arabian Sea. It may also cause floods in the region's complex river systems that will affect the existing development and poverty reduction initiatives. Coupled with high population density levels, these climate shifts have the potential to create complex environmental, humanitarian, and security challenges.

The IPCC 4th Assessment Report states that South and Southeast Asia is expected to be severely affected by the adverse impacts of global climate change since economies of most countries in the region are relying heavily on agriculture and natural resources. South Asia and Southeast Asian region is annually witnessing events of climate extremes, particularly droughts, floods and tropical cyclones. At the same time large areas of the region are influenced by monsoon and highly prone to flooding.

It is expected that in the next 30 to 50 years, the Southeast Asia will face the worst impacts of global warming. Consequently, such climatic impacts will severely threaten the livelihood of poor people living in rural and coastal areas with limited adaptive capacity. According to recent predictions, increased global warming is expected to significantly impact working people and productivity in Southeast Asia by 2045. Rising temperature will also increase the no. of unsafe 'heat stress' days annually, which will adversely affect vulnerable workers, and have a negative impact on regional economies.

The changes in the global climate will have sever and wide-ranging impacts on our natural environment, water resources, food supply, land, infrastructure and the increase in extreme weather events, socio-economic activities and related sectors. It would also affect our natural biodiversity, terrestrial/aquatic ecosystems, agriculture productivity and food security, human health and coastal zones. The predicted changes in rainfall pattern due to climate change (spatial and temporal) are likely to severe water shortages or cause flooding in many areas.

Due to rise in temperature, melting of mountainous ice glaciers can cause soil erosion and flooding downstream. The rise in atmospheric temperatures may cause shifts in crop growing seasons and cropping pattern which may affect food security. Increasing temperature due to global warming has the potential to severely increase rates of extinction for many natural habitats and vulnerable species (projected up to 30 per cent loss with a 2°C rise in temperature). This would particularly affect coral reefs, boreal forests, Mediterranean and mountain habitats. Increasing sea levels in coastal areas mean greater risk of storm surge, inundation and damage to coastlines due to high waves, particularly in small islands and countries with low lying deltas.

Based on IPCC Reports and various studies, the probable and projected impacts of global climate change on some of the main sectors such as impacts of global warming on sea level rise, biodiversity, glaciers, floods, agriculture and human health in the South Asia and Southeast Asian region have been discussed below.

III. Sea Level in Coastal Areas

The South Asian region (SAR) is extremely vulnerable to sea level rise, cyclone, floods, droughts and landslides in hilly areas. The remote and rural areas have low access to clean and modern efficient energy services. So, even small increases in Earth's temperature caused by climate changes can have severe impacts on them. It has been estimated that the earth's average temperature has gone up by 1.4°F over the past century and is expected to rise as much as 11.5°F over the next century. This might not seem like a lot, but the average global temperature during the last Ice Age was about 4° F lower than it is today.

The rising sea levels due to melting of polar ice caps contribute to greater storm damage; warming ocean temperatures are associated with stronger and more frequent storms. Increased rainfall, particularly during severe weather events, may leads to flooding and may cause damage to life and infrastructure. An increase in the incidence and severity of wildfires threatens natural biodiversity, habitats, homes and lives; heat waves may contribute to human deaths and other consequences.

As reported by IPCC various studies have projected that sea level rise could flood the coastal residential areas of millions of people living in the low lying areas of South, Southeast and East Asia such as in Sri Lanka, Vietnam, Bangladesh, India and China (Wassmann *et al*. 2004, Stern 2006, Cruz *et al*. 2007). A rising sea levels due to global warming will increase the amount of loss of land and people displaced due to permanent inundation in the coastal areas. It might also have some major impacts on national, regional and even the global economy, as coastal areas are not only amongst the most densely populated areas, but in many cases are the location of some of the critical infrastructure such as sea ports, industrial facilities, oil refineries, etc.

Already global warming has resulted in an increased cyclonic activity, sea level rises displacing people, flooding, and the reduction in the sea food due to the acidification of the waters. Thousands of people have been displaced by ongoing sea level rises that have submerged low-lying islands in the Sundarbans. A one meter sea level rise is projected to displace approximately 7.1 million people in India and about 5,764 Km^2 of land area will be lost, along with 4200 Km of road. Around seven million people are projected to be displaced due to submersion of parts of Mumbai and Chennai if global temperatures were to rise by as low as 2°C.

IV. Agriculture

An assessment report (2009) released by the International Fund for Agricultural Development (IFAD) predicted that in the South and Southeast Asia, agriculture and natural resource management will be seriously affected by the adverse impacts of climate change. According to IFAD report, events of climate extremes, such as droughts, floods and cyclones, would severely impact irrigation systems, soil degradation, loss of natural ecosystems, crop productivity, crop yields, loss of natural wild life habitat and fresh water resources. This will have adverse impacts on developing and underdeveloped countries such as India, Sri Lanka and Bangladesh, relying heavily on agriculture and natural resources. These climate impacts will also severely threatens livelihoods of local people, depending extensively on agricultural production.

In the same year, the Asian Development Bank (ADB) released a report on the economics of climate change in Southeast Asia. According to the ADB report (2009), Southeast Asia is particularly vulnerable to climate change, due to large number of the population living under poverty, its heavily populated coastlines and large agricultural sectors.

The agriculture sector accounted for nearly 43 percent of total employment in 2004, and contributed to about 11 percent of GDP in 2006, within the Southeast Asian region. The region is also highly dependent on natural resources and forestry products and these exports are likely to be adversely affected by extreme weather events due to climate change.

The Asian Development Bank report further predicted that rice yields were likely to decline by up to 50 percent on an average by the year 2100 compared to 1990. Many countries such as Vietnam and Thailand are expected to be the most affected by this decline. In addition, rising sea levels could also result in the loss of about 12 percent of rice production in the region. The climate change is expected to adversely affect the agriculture sector in South and Southeast Asia in several ways. For example, changes in rainfall and runoff, and subsequently, water quality and water supply may severely affect irrigation systems in the region. The region is already under water stress and future climate change effects on regional rainfall will therefore have both direct and indirect impacts on agriculture productivity.

As per predictions, when the region is facing 2-4 °C temperature changes, studies suggest the potential for both gains and losses. For example, for less than 2 °C, agricultural losses are experiences in the Philippines, while rice yields in Indonesia and Malaysia are projected to increase.

However, climate change studies generally indicate increasing rainfall throughout much of the region. But even with rainfall increases, temperature increase may threaten agricultural productivity, stressing crops and reducing yields. The scientific studies have projected, particularly, a high sensitivity of major cereals and tree crops due to changes in temperature, moisture, and carbon dioxide concentration for the region. As for example, projected impacts on rice and wheat yields indicate that any increases in production associated with CO_2, fertilization will be more than offset by reductions in yield resulting from temperature and/or moisture changes. Such agricultural impacts would particularly affect low-income rural population that depends on traditional agricultural systems or on marginal lands for their livelihood. The food security for the people is the primary concern in the region since most of the rural poor people depend heavily on agriculture for their livelihood.

The global warming is causing changes in the intensity of rainfall events, and the break cycles of the monsoon, combined with an increased risk of critical temperatures being exceeded more frequently, could significantly change cropping pattern and crop yields. In fact, spatial and temporal changes in the temperature coupled with water stress will have key implications for agriculture production, in particular, for falling crop yields. The impacts of climate change on agriculture will vary according to locality, but models project a 15-30 % decline in the crop productivity of most cereals and rice across the region. For example, when the region is facing with 2-4°C temperature increase, rice yields are expected to decline by about 0.75 tons/ha.

The studies have also shown that the overall crop yields are expected to decrease up to 30% in the region by mid 21st century. The most dramatic negative impacts are expected in the arid zones and flood affected areas, where agriculture is already at the edge of climate tolerance limits. Furthermore, the demand for water for irrigation of agricultural fields in arid and semi-arid regions is likely to increase by about 10% for temperature increase by 1%.

It has been estimated that even though the impact of climate change could cause significant changes in crop production, crop yields, storage and distribution. The ultimate effect of the climatic changes in the region is uncertain mainly because of local differences in crop growing season, crop irrigation, crop management, etc. The non-inclusion of possible crop diseases, microorganisms affecting crops and pests, in crop model simulations and the vulnerability of agricultural areas to episodic environmental hazards, including floods, droughts and cyclones also affects the outcome. In such situation, low-income rural population that rely on traditional agricultural systems or on marginal lands are particularly vulnerable to the impacts of climate change (IPCC 4th Assessment report).

V. Ecosystems and Biodiversity

In recent years, natural ecosystems in South and Southeast Asia's have been put under enormous pressures to support the ever growing demand for supply of direct and indirect consumable materials due to increasing population, industrial activities, urbanization, demand for timbers, etc. The most affected areas are coastal and marine ecosystems, natural forests, mountainous regions, flora and fauna within them. The climate change will have a profound effect on the future distribution, productivity, and health of forests throughout Asia and Southeast Asia, as for example, northeast China may become deprived of conifer forest. It has been estimated that the productivity of grassland ecosystem is expected to decline by as much as 40-90 per cent for an increase in average temperature of about 2-3°C, combined with reduced precipitation, in the arid and semi-arid regions.

There are various studies that reveal that in the 20th century global warming has already directly affected our natural ecosystems, as for example, many species have been moving pole-wards, seasonal events such as flowering or egg-laying have been occurring several days earlier each decade. The bleaching of Coral reefs has become increasingly prevalent since the 1980s. It has also been estimated that nearly 30 percent of coral reefs could be lost in the next 10 years (Cruz *et al*. 2007). The loss may be as high as 88 per cent (59 per cent of global) in the next 30 years in some areas (Sheppard 2003; Wilkinson 2004). Overall it is estimated that global climate change has already contributed to the extinction of over 1% of the world's amphibian species from tropical mountains.

In the future, it is expected that for many species, the rate of warming will be too rapid and too high to withstand the changes. A warming world due to climate change will also have severe consequences for many species as it will accelerate species extinctions and has the potential to lead to the irreversible loss of many vulnerable and endangered species around the world, with most kinds of animals and plants affected. The rising levels of carbon dioxide have some direct impacts on natural ecosystems and rich biodiversity, but increases in temperature and changes in rainfall pattern will have even more profound effects. Many endangered, rare and vulnerable species in natural ecosystems are likely to disappear almost completely at even moderate levels of global warming.

Natural ecosystems and its rich biodiversity in the South and Southeast Asia region represent a key asset contributing to the regional economy by providing food, water and other products that sustain human life. Natural resources such as medicinal plants, timber products and fisheries also support commercial enterprises in the entire region. As a result the degradation and loss of natural ecosystems poses a serious threat to the economic, social and cultural stability of the region since most of the poor and rural community is heavily dependent upon the products of such ecosystems. The survival of many species has already been threatened due to land-use changes, land degradation, loss of biodiversity, over-exploitation of water resources and other natural resources, contamination of inland and coastal water bodies.

Many scientific studies suggests that climate change leading to sea level rise, increasing sea surface temperatures and acidification of the oceans will entail a loss of mangrove forests, wetlands, and reduced fish stocks throughout this region. The tropical and temperate forests are particularly affected due to climate change. Coral reefs may be able to keep up with the rate of sea-level rise but may suffer bleaching from higher temperatures. For example, the 1997-1998 El Nino event caused widespread bleaching of coral reefs in the Southeast Asian region including Indonesia,

Cambodia, Malaysia and Thailand. Landward migration of mangroves and tidal wetlands is expected to be constrained by infrastructure and human activities (IPCC 4th Assessment report).

The mangrove communities are severely affected by sea-level rise, change in rainfall patterns and runoff that change the flow of freshwater to the coastal zone and, consequently, the distribution of proper saline habitat for mangroves forests. The projected increases in the rate of evapo-transpiration and rainfall variability are likely to have a negative impact on the viability of freshwater wetlands, resulting in shrinkage and desiccation.

Several studies on climate change also suggest that some of the natural forests and vegetation in South and Southeast Asia may experience some positive effects due to climate change. In addition, climate change is expected to change disturbance regimes within forest communities, affecting the frequency and intensity of pest outbreaks and wildfire. The expected changes in the distribution and health of rainforest and drier monsoon forest will be complex, for example, in Thailand the area of tropical forest could increase from 45% to 80% of total forest cover (Boonpragob, K., Santisirisomboon, J., 1996).

Anthropogenic pressures together with changing hydrology are having a discernible impact on the productivity and resilience of South Asia's ecosystems. Some of the most significant sites threatened by global warming, are the Terrai grasslands, forests of the southern Himalayas, biosphere in the Western Ghats; and the Sundarbans wetlands of West Bengal and Bangladesh. The mountain ecosystems are expected to be the most affected by the climate change. The Himalyan ecosystems are vulnerable to Glacial Lake outburst, floods and flash floods.

The changes in the forest distribution, health of rainforest and drier monsoon forest are foreseen. In Sri Lanka, for example, a significant increase in dry forest and a decrease in wet forest could occur. Moreover, increased dryness during pre-summer season may speed up the incidences of forest fire. Potential increases in evapo-transpiration and rainfall variability are expected to have a negative impact on the viability of freshwater wetlands, resulting in shrinkage and desiccation. In particular, regional studies have projected a loss of about 54,900 km^2 of wetland in the region. Sea-level rise and increases in sea-surface temperature are the most probable major climate change-related stresses on coastal ecosystems.

VI. Coastal Areas

The coastlines of South Asia and Southeast Asia are highly vulnerable to the effects of climate change due to the geology and geography of the region's coastal areas, the growing population density and presence of coastal infrastructure in the coastal zone. Moreover, large tidal variations, tropical cyclones, coupled with the potential increase in regional rainfall, suggest the probability for increased coastal hazards.

Sea-level rise and increases in sea-surface temperature are the most probable major climate change-related stresses on coastal ecosystems. Densely populated, heavily settled and intensively used low-lying coastal plains, deltas and islands are especially vulnerable to coastal erosion, land loss, inundation and sea flooding, upstream movement of the saline/freshwater front and seawater intrusion into freshwater aquifers. The impacts of sea level rise will be mostly felt in low-lying areas of Indonesia, Philippines, Myanmar, Vietnam, Thailand and Malaysia as well as large deltaic regions of Bangladesh, Maldives and east India by poor rural people, where significant economic and social disruption will occur, with environmental refugees further pressing already stressed cities.

The consequences of climate change will change conditions and undermine livelihoods in many areas. The World Bank issued a press release (2013), warning that warmer weather due to rise in temperature, could threaten livelihoods in Southeast Asia. It predicted the degradation of coral reefs, which is likely to diminish tourism, reduce fish stocks and leave coastal communities more vulnerable to storms. The World Bank's 2014 report released by the Intergovernmental Panel on Climate Change (IPCC), warned that people living in coastal regions of Asia could face some of the worst effects of global warming. It is expected that millions of vulnerable people living in these areas are likely to lose their shelter, homes and settlements due to flooding and famine. The extreme climate events and deteriorating environmental conditions are likely to force many to leave their homes temporarily or even permanently for another village, city, region or country.

Socio-economic impacts could be felt in major coastal cities, ports and tourist resorts, commercial and small scale fisheries, coastal agriculture and infrastructure development. Other consequences will include increased salinization of surface water and groundwater, loss of wetlands such as the Sundarbans and public health risks. International studies have projected the displacement of several million poor people from the region's coastal zone, even in the event of a 1 m rise in sea level. The costs of response measures expected to reduce the probable impact of sea-level rise (30-50 cm) in the region could amount to millions of dollars per annum (IPCC 4th Assessment report).

VII. Cyclones

India has a long coastline of about 7500 km, with the Arabian Sea and the Bay of Bengal and is

therefore, very susceptible to cyclonic activity. The coastal areas of India are densely populated with people who are totally dependent on the sea for their economies and food supply, as a result highly vulnerable to the effects of global warming. Therefore, any damage to the natural cycle of the sea is expected to severely affect the people of coastal India. Cyclones have been observed to be more frequent in the Bay of Bengal than the Arabian Sea. Consequently the states of Andhra Pradesh, Orissa, Tamil Nadu and West Bengal, along the Bay of Bengal are the most affected areas due to cyclone. Some of the most notable cyclones in Indian history include the 1737 Hooghly/Calcutta cyclone, 1970 Great Bhola cyclone, 1839 Coringa Cyclone and 1876 Great Backerganj Cyclone which affected more than a million people. It has also been observed that as a result of global warming, the average number of Category 4 and Category 5 hurricanes per year has increased over the last 30 years.

The National Institute of Oceanography (NIO), under the Council of Scientific and Industrial Research (CSIR), Government of India, carried out a scientific research on the impacts of climate change on sea level, to assess the degree to which mean sea level changes and the occurrence of extreme events may change. The study concluded that an increased occurrence of cyclones in the Bay of Bengal, particularly in the post-monsoon period, along with increased maximum wind speeds associated with cyclones and a greater number of high surges under climate change have been observed. In addition, the strength of tropical cyclones, which represent a threat to the eastern coast of India and coastal area of Bangladesh, is also likely to increase.

VIII. Migration of People

Although the precise influence of climate change on migration of people is not known and is still the subject of scientific inquiry and debate. The range of issues facing the region calls for a comprehensive assessment of climate change, migration, and their impact on both traditional and human security. The Asian Development Bank report (2012) "Climate Change and Migration in Asia and the Pacific" concludes that while uncertainties exist on where, how and how many people will be displaced by the impacts of climate change, it is imperative to begin aggressively examining emerging climate challenges to avoid future complex crisis scenarios. The extreme vulnerability of South Asia and Southeast Asia raises concern of potential changes and increases in both internal and international migration across the subcontinent. In areas of existing conflict in South Asia and Southeast Asia added stressors of climate change and changing migration patterns could be a security concern.

The deteriorating environmental conditions could increasingly influence decisions to migrate, in addition to social, political, economic and demographic factors. Sudden onset and slow-onset of climate change events could trigger migration in Bangladesh, India, Sri Lanka, Vietnam and other neighbouring countries. It is also expected that sudden-onset of climatic events such as flooding, cyclones and storm surges could displace millions of inhabitants within short periods of time, as recent events in India and Bangladesh demonstrate. The slow-onset of climatic events such as changes in precipitation, sea level rise and land erosion could have detrimental impacts on some of the key economic sectors such as agriculture, fishing and tourism, influencing someone's decision over time to migrate for greater economic opportunity.

Recent natural disasters in South Asia demonstrate what could be a more frequent reality for the region. Floods in September 2012 displaced about 1.5 million people in the northeastern state of Assam, while Cyclone Aila in 2009 displaced nearly 2.3 million people in India and almost 850,000 people in Bangladesh.

IX. Water Resources

The impact of climate change is most strongly felt through changes in the distribution of water around the world and differences in water availability between regions will become increasingly difficult. The region already faces water stresses and many areas are often dependent upon limited availability of groundwater and rainfall collection. Maintaining the security of fresh water resources is a key priority for the South Asia and Southeast Asian poor rural population. Climate change will further aggravate water shortage by extreme events such as droughts which undermine food security, or extreme rainfall events which increase the risk of flooding. Challenges to water resources management will therefore be exacerbated by sea-level rise which contribute to salt-water intrusion into available freshwater resources in the coastal areas. Scientific assessments have projected changing patterns of runoff and river flows in the region in the next decades, as well as increase in water management costs and number of poor rural people affected by water stress.

In particular, a reduction in flow of snow-fed rivers, coupled with increases in peak flows and sediment yields, may have serious implications on hydropower generation, urban water supply and agriculture. Water availability from snow-fed rivers could increase in the short term but decrease in the long term. Runoff from rain-fed rivers may change in the future, although a reduction in snowmelt water would result in a decrease in dry-season flow of these rivers. The requirements of water for larger populations and increasing demands in the agricultural, industrial, and hydropower sectors will put additional stress on available water resources. The pressure will be most

evident on drier river basins and those subject to low seasonal flows.

Availability of fresh water is highly seasonal, with about 75% of the annual rainfall occurring during the monsoon months. Water supplies will be threatened by higher temperatures, changes in river regimes, and greater incidence of coastal flooding. In particular, water availability is expected to decrease dramatically especially in dry season. The main consequences of expected climate change impact is melting of glacier in Himalayas, which is projected to increase flooding and affect water resources aggravating seriously the conditions of poor rural people reliant on them. Water from Himalayan glaciers - which plays a key role in the provision of water to the region and snowfields currently supplies up to 85% of the dry season flow of the great rivers of the Northern Indian Plain. This could be reduced to about 30% of its current contribution over the next 50 years, if forecast of climate change and glacial retreat are realised. This will have major implications for water management and irrigated crop production.

Furthermore, temperature and increased seasonal variability in precipitation are projected to result in accelerated recession of glaciers and increasing risk from glacial lake outburst floods. A reduction in flow of snow-fed rivers, accompanied by increases in peak flows and sediment yields, would have major impacts on hydropower generation, water supply, and agriculture.

Hydrological changes in island and coastal drainage basins are expected to be small, apart from those associated with sea-level rise. However, national studies suggest for both gains and losses due to projections of increased runoff in some river basins in response to increasing rainfall. For example, water stress in the Mekong Delta rises, and water shortages in the Philippines may fall. As per the IPCC 4th assessment report, regional studies state that a loss of 1.7 billion USD in total costs in the water resources sector is associated to projected 2% temperature increase, and an increase by 7-924 million of the number of poor rural people experiencing water stress associated to 2-4% of temperature increase (IPCC 4th Assessment report).

X. Floods and Droughts

Under climate change scenario, predicted rainfall increases over most of Asia and Southeast Asia region, particularly during the summer monsoon. This could further increase flood-prone areas in East Asia, South Asia and Southeast Asia. In Central and South Asia, crop yields are predicted to fall by up to 30 per cent, creating a very high risk of hunger in several countries.

The entire South Asian region suffered from flood in 2007 that was so devastating, that it annihilated and destroyed large areas in Bangladesh, Nepal, Bhutan, India and Pakistan. It's most devastating effects were observed in Southern India, where it lasted for more than 15 days, killing more than 2000 people and affecting another nearly 30 million people. The situation was termed by UNICEF to be 'the worst flooding of South Asian region in living memory'.

The recent catastrophic climatic events such as the massive floods in India and Pakistan, Hurricane Katrina in the United States, prolonged droughts in Australia, China, India, Pakistan and Texas in United States, are all the results of increased temperatures due to global warming. It has been noticed that during the 21st century, climatic disasters has occurred five times as frequently and killed or affected nearly seventy times as many people. Research studies have also indicated that between the year 2000 and 2004, an average of 26 climatic disasters was reported each year. Thus, the extreme climatic events will continue their destruction unabated if steps to mitigate the impacts of global warming are not taken at the earliest and in an effective manner.

As explained above, the process of global warming has such an impact on the climate that it increases the severity of precipitation at one time, and minimizes it in the other. Therefore, this process has resulted in severe drought like conditions in India, with tens of millions of deaths resulting from it in the past few centuries. India depends heavily on prolonged and optimum monsoons for its agricultural productivity, failure of which results in the decreased crop productivity, leading to droughts. Out of the total agricultural land in India, about 68% is prone to drought of which 33% is chronically drought prone, receiving rainfall of less than 750mm per year, particularly in the states of Maharashtra, Gujarat, Rajasthan, Karnataka, Andhra Pradesh and Orissa. The World record of drought was in 2000 in Rajasthan, India. According to researches, unabated global warming will lead to exacerbation of the droughts, cutting down the water availability in the plains of Uttar Pradesh and Bihar. India's initial communication to the United Nations Framework Convention on Climate Change (UNFCCC) projected that Luni, the west flowing river of Kutchh and Saurashtra are likely to experience acute physical water scarcity. The river basins of Mahi, Pennar, Sabarmati and Tapi are also likely to experience constant water scarcities and shortages.

XI. Glaciers

As discussed earlier, global warming is causing the melting of ice glaciers in the Himalayas and other ice deposits. In the short term, this means increased risk of flooding, soil erosion, mudslides, landslides and Glacial Lake Outburst Flood (GLOF) in Nepal, Bhutan, Bangladesh, Pakistan, and north India during the wet season. The term 'GLOF' refers to the glacier floods

caused by the drainage of naturally dammed lakes in the glaciers on/at the margin of glaciers. Because the melting of snow coincides with the summer monsoon season, any intensification of the monsoon and/or increase in melting is likely to contribute to flood disasters in Himalayan catchments.

In the longer term, global warming could lead to a rise in the snowline and disappearance of many glaciers causing serious impacts on the populations relying heavily on the 7 main rivers in Asian region fed by glaciers melt water from the Himalayas. Throughout Asia one billion people could face water shortage leading to drought and land degradation by the year 2050s (Christensen *et al*. 2007, Cruz *et al*. 2007).

XII. Health

Human health will be strongly affected by climate change, as worldwide deaths from malnutrition and heat stress are likely to increase and vector-borne diseases could become more widespread. A rise in extreme weather events will have severe effects on health and lives as well as associated environmental and economic activities. The changes in the distribution of vectors borne diseases may bring more people at risk from diseases such as high fever due to dengue, malaria and chikungunya.

According to WHO assessment report, climate change affects the social and environmental determinants of health such as clean air, fresh and safe drinking water, sufficient food and secure shelter. Between 2030 and 2050 climate change is expected to cause approximately 250,000 additional deaths/year from malnutrition, malaria, diarrhea and heat stress.

In Asia, the principal impacts of climate change on health will be on epidemics of malaria, dengue, and other vector-borne diseases (Martens *et al*. 1999). The global burden of climate change-attributable diarrh0oea and malnutrition are already the largest in the world in Southeast Asian countries including Bangladesh, Bhutan, Nepal, India, Maldives and Myanmar in 2000. Illness and death are expected to increase from diarrhoea diseases due to drought and flooding, and are also expected from increased amounts of cholera bacteria in coastal waters. Climate change leading to an increase in the frequency and duration of severe heat waves and humid conditions during the summer season is likely to increase the risk of mortality and morbidity, mainly in the old and urban poor populations of temperate and tropical Asia (Epstein *et al*. 1995) and high temperatures and poor urban air quality, such as in Chongqing, China and in Jakarta, Indonesia, could contribute to widespread heat stress and smog induced illnesses in urban populations (Cruz *et al*. 2007).

XIII. Impacts on Productivity

According to the Indira Gandhi Institute of Development Research, if the process of global warming continues to increase, resulting climatic disasters would cause a decrease in India's GDP to decline by about 9%, with a decrease by 40% of the production of the major crops. A temperature increase of 2° C in India is projected to displace seven million people, with a submersion of the major cities of India like Mumbai and Chennai. The Asian Disaster Preparedness Center recently reported that Bangladesh "is already under pressure from increasing demands for food and the parallel problems of depletion of agricultural land and water resources from overuse and contamination. Climate variability and projected global climate change makes the issue particularly urgent."

Worst hit will be Singapore and Malaysia, which could experience decreases in productivity by up to 25 per cent. Expected decreases in productivity will vary across the region, with Indonesia predicted at 21 percent, Cambodia and the Philippines at 16 percent, and Thailand and Vietnam at 12 percent.

Fisheries activities in both fresh water and sea water could be severely affected. Fisheries at higher elevations are likely to be adversely affected by lower availability of oxygen due to a rise in surface air temperatures. In the plains, the timing and amount of precipitation could also affect the migration of fish species from the river to the floodplains for spawning, dispersal, and their growth (FAO 2003). Sea level rise and changes in sea water temperature, salinity, wind speed and direction, strength of upwelling, mixing layer thickness and predator response to climate change have the potential to substantially alter fish breeding habitats and food supply for fishes and ultimately the abundance of fish populations in Asian waters with associated impacts on coastal economies (Cruz *et al*. 2007).

If Southeast Asia fails to engage in sustainable development practices and disaster risk management, regional growth and poverty eradication will be severely impacted. While many Southeast Asian countries have taken steps to tackle the impacts of climate change, more needs to be done to protect people, livelihoods and economies. The region needs to employ a number of adaptation measures, encouraging low-carbon growth, raising public awareness, funding additional climate change research, and enhancing policy planning. In the long-term, this might help to mitigate the effects of climate change, and in return, help safeguard regional economies and livelihoods.

Ecological infrastructure involves using natural landscapes and ecosystems for the benefit of society. In the case of climate change, natural landscapes that mitigate the consequences of flooding, water salinization, and erosion may be both cost effective and more resilient than traditional infrastructure, such as levies and pumps. Residents of India and Bangladesh

have been innovating ecological infrastructure due to lack of formal structures in many areas.

XIV. Conclusion

The climate change is resulting due to the impact of global warming phenomenon induced by greenhouse gases emissions. The predictions of change in global average temperatures due to climate change by the year 2100, ranges from a minimum temperature rise of about 1.4°C to as much as 5.8°C. The effects of global warming have also caused damage to coastal infrastructure, aquaculture and coastal tourism. The natural ecosystem such as grass lands, aquatic ecosystems like mangroves and coral reefs have also been affected by the climatic change. The global climate change would impact natural biodiversity, productivity, ice deposits on mountains and polar glaciers, sea level rise, economic activities and infrastructure in coastal areas, human health, etc. The process of global warming has affected South Asia and Southeast Asian countries intensely, destroying its economy and depriving its people of their basic needs like food and shelter. The current patterns of destructive floods, increasing intensity of cyclones, recurring droughts and the increasing temperatures are all the results of global warming.

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Palynology and Stratigraphy Relationship of the Facies Intertongueing between the Afikpo Sandstone and Nkporo Shale in the Cretaceous Anambara Basin, Southeastern Nigeria

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Keywords: nkporo group, intertongueing, afikpo sandstone, nkporo shale/afikpo sandstone, campanian-early maastrichtian and intercalation.

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Two palynological zones: *Milfordia spp* acme zone I characterized by relative high abundance of *Milfordia* spp. such as *Milfordia* sp. and *Milfordia jardinei*, dated Campanian and the overlying *Foveotriletes margaritae zone* II characterized by paucity *of Milfordia* spp. and co-occurrence of *Monocolpopollenites sphaeroidites, Syncolporites* sp., *Ephedripites* sp., and *Monosulcites* sp.; dated Early Maastrichtian age. The age dating and the stratigraphic lithofacies is equivalent to Nkporo Shale/Afikpo Sandstone known for Afikpo Basin stratigraphy but here reported newly in the Anambra Basin. This suggests lateral facies intertongueing of Afikpo Sandstone characterized by erosional surfaces, unconformable with Nkporo Shale, extended into Anambra Basin. The result reveals a new sandstone member in the Nkporo Formation or in another way makes Nkporo Formation to become Nkporo Group comprising of Nkporo Shale and Afikpo Sandstone.

Keywords: nkporo group, intertongueing, afikpo sandstone, nkporo shale/afikpo sandstone, campanian-early maastrichtian and intercalation.

I. Introduction

The full knowledge of the statigraphy of Anambra Basin is still a mirage considering the complexity of the lithofacies in both vertical and lateral relationship. The Ubiaja-1 well is located in the Anambra Basin, Delta State, Nigeria (Fig. 1). A considerable lower section of it had earlier been investigated by Ola-Buraimo *et al,* (2015). In this study the upper part of the well is being investigated to further elucidate the lithofacies sequence and to determine both the palynostratigraphy and paleo environment of deposition of the sediments. Detail investigation shows that there is much complexity attached to the understanding of the stacking patterns of contemporaneous sediments, thereby making it virtually difficult to emphatically say that the formations are composed of a particular sequence in one location compared to the other. A study of the Ubiaja-1 well revealed two important information in terms of age dating which varies from the oldest sediment of Eze-Aku Formation dated Turonian (Ola-Buraimo *et al,* 2015) and the uppermost part of this study which indicates Nkporo/Afikpo Formation which has never been reported for Anambra Basin but only for Afikpo Basin (Nwajide, 1990). A lithostratigraphic sequence of over 300ft shows that younger formations such as Mamu, Ajali, Nsukka, Imo, Ameki and Ogwashi-Asaba Formations are not present. This raises a lot of concern and why they are missing from the established sequence of Anambra Basin up to the near surface of the studied well.

Palynological study of this well has raised another dust in terms of what could have been responsible for the non-deposition or removal of such thick pile of sediments involving several formations. A conclusive statement cannot be made here but it could suggest another phase of tectonic activity that has not been noticed and reported in the Anambra Basin. After the Early Maastrichian deposition of the Afikpo Sandstone, it was followed by period of structural readjustment leading to tectonic activity whereby there was local upliftment of the Ubiaja syncline into a platform; that is from a graben into a horst compared to

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its adjacent structural blocks. However, this idea is at a premature stage because it lacks enough data probably due to inadequate sampling and poor marker palynomorph recovery which needs further investigation by collecting more samples from the area to corroborate results obtained from this study. However, a new Stratigraphy is suggested for the Nkporo Formation to become Nkporo Group comprising of Nkporo Shale and Afikpo Sandstone.

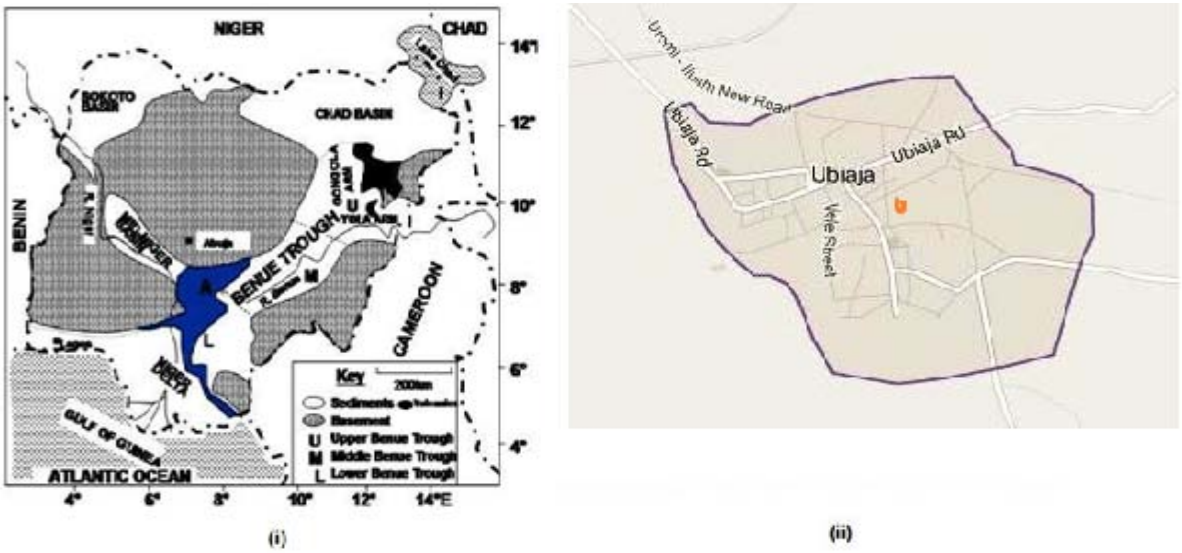


Fig. 1: (i) Generalized geological map of Nigeria showing Anambra Basin [Whiteman, 1982; blue color-A]; (ii) location map of the Ubiaja -1 well in Anambra Basin (Adopted from Ola-Buraimo *et al.,* 2015)

II. Geologic Setting

The Anambra Basin is believed to be the lower section of the Benue Trough, an intracratonic basin, trending NE-SW, folded and aborted rift basin that runs obliquely across Nigeria. Its origin was linked to the tectonic process that accompanied the separation of the African and South American plates in the Early Cretaceous (Murat, 1972; Burke *et al.,* 1972). Structurally, the evolution of the Anambra Basin has been described by some researcher (Nwachukwu, 1972; Ojoh, 1988; Popoff, 1990; Fairhead and Binks, 1991; Obi *et al.,* 2001; Obi and Okogbue, 2004). Prior to the tectonic event, the Anambra Basin was considered to be a platform; that was thinly covered by sediments while the Abakaliki Synclinorium was an axis of active sedimentation. Recently, understanding the stratigraphy of the Anambra Basin has shown that this assertion might not be widely applicable to the whole basin rather a local aspect of it. This is because oldest sediments of Albian to Upper Cenomanian age (Ola-Buraimo and Akaegbobi, 2013b) within the basin at a great depth has proved that when there was active sedimentation in the Abakaliki Synclinarium, the same active sediment deposition was also taking place in some other parts of the Anambra Basin.

There is an old school of thought which believes that the folding of the Abakaliki Anticlinorium led to lateral shifting of the depositional axis into the Anambra Basin which began to accumulate sediments shed largely from the Abakaliki Anticlinorium (Murat, 1972; Hoque and Nwajide, 1985; Amajor, 1987). Also, this explanation given for the post Santonian deposition of sediments in the Anambra Basin lacks logical reasoning and simple geological law of superposition. Firstly, pre-Santonian sediments which include Asu River Group, dated Albian to Lower Cenomanian (Ola-Buraimo and Akaegbobi, 2013b); Eze-Aku Formation, dated Upper Cenomanian-Turonian (Ola-Buraimo, 2013a); and Awgu Formation, dated Coniacian (Ola-Buraimo, 2013c) have been found present in the Anambra Basin. Secondly, the sediments claimed to have been shed from Abakaliki Anticlinorium to Anambra Basin after Santonian tectonics suppose to have been deposited in reverse order of the youngest sediment (Awgu) being eroded first from the top and deposited, followed by Eze-Aku and Asu River at the top. However, this is not the case.

Thirdly, Stratigraphy rule applies that in reworked sediment like that suggested for Anambra Basin (Murat, 1972; Hoque and Nwajide, 1985) should contain both older and younger fossils, where the younger fossil takes precedent over the older fossil in dating the formation. Ola-Buraimo *et al,* (2015) reported that all pre Santonian formations dated palynologically did not show any evidence of reworking which should have shown admixture of older and younger fossils. Such reworked sediment was only reported in the Neogene Ogwashi-Asaba Formation (Ola-Buraimo and Akaegbobi, 2012).

The lithostratigraphic framework for the Early Cretaceous-Oligocene strata in the southeastern Nigeria

has been summarized by Nwajide, (1990; Table 1). Various authors including Arua, (1986); Anyanwu and Arua, (1990); Fayose and Ola, (1990) have suggested a progressive deepening of the basin from lower coastal plain and shoreline deltas to shoreline and marginal marine deposits. The resulting post Santonian stratigraphy succession comprising of Nkporo Group, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Formation, Ameki Formation and Ogwasi-Asaba Formation is presented in Table 1. The detailed stratigraphic descriptions of the formations have been reported by many authors (Petter, 1978; Ladipo, 1985; Agagu *et al.,* 1986; Reijers, 1996; Ola-Buraimo and Akaegbobi, 2012, 2013b).

Table 1: Correlation chart for early cretaceous strata in southeastern Nigeria (Modified after Nwajide, 1990)

Age	Abakaliki-Anambra Basin		Afikpo Basin
30M.Y	Oligocne	Ogwashi-Asaba Formation	Ogwashi-Asaba Formation
54.9	Eocene	Ameki/Nanka Formation Nsuegbe Sandstone (Ameki Group)	Ameki Formation
65	Paleocene	Imo Formation Nsukka Formation	Imo Formation Nsukka Formation
73	Maastrichtian	Ajali Formation Mamu Formation	Ajali Formation Mamu Formation
		Nkporo Oweli Formation/Enugu Shale	Nkporo Shale/Afikpo Sandstone
83	Campanian		
87.5	Santonian	Non-deposition/erosional	Non-deposition/erosion
88.5	Coniacian	Agbani Sandstone/Awgu Shale	Non-deposition/erosion
93	Turonian	Eze Aku Group	Eze Aku Group (include Amasiri Sandstone)
100	Cenonian-Albian	Asu River Group	Asu River Group
119	Aptian Berremian Hauterivian	Unnamed Group	
Precambriam		Basement Complex	

III. Materials and Methods

Detailed lithostratigraphy description was carried out on fifty two samples under the microscope in the laboratory. The lithological description followed international standard by considering the type of facies, colour, textural parameters such as grain size, roundness, and sorting. Other important features noted are fossil contents, post depositional effect (diagenesis) and presence of calcite or authigenic minerals such as glauconite or pyrite.

The materials used for the palynological analysis are mortar and pestle, weighing balance, sample plastic cups, pipettes, 5 micron sieves, centrifuge, fume cupboard, Branson sonifer 250, distilled water, test tubes, glass slide and cover slip, hydrochloric acid (HCl), hydrofluoric acid (HF), filter paper, glycerine ($C_3H_8O_3$), 250 ml polypropylene beakers, Nitric acid (HNO_3), zinc bromide ($ZnBr_2$), TPX (a mounting medium), potassium hydroxide (KOH) and personal protective wears such as safety gloves, glasses and coverall. Fifteen samples were selected and taken at irregular interval because some of the intervals are missing. Therefore, 10 g of the samples were soaked overnight in Hydrofluoric acid (HF), and stirred intermittently for effective digestion.

To completely remove the fluoro-silicate compounds that usually form from the reaction with HF, the content was again treated with warm 10 % HCl and finally completely neutralized with distilled water. Sieving process with 5µm mesh was undertaken in order to remove clay particles present, enhance collection of the debris and to achieve clean slide making. The retrieved debris of the samples was mildly oxidized, followed by heavy mineral liquid separation of the macerals using zinc bromide ($ZnBr_2$) at 2.1g/cc. The collected residue was mounted on glass slides with DPX. The preparation method was in accordance with standard methods (Traverse, 1988; Wood *et al.,* 1996). Important forms including pollen and spores photographs were taken with Nikon Koolpix P6000 digital camera.

IV. Results and Discussion

a) Lithology Description

i. *Lithostratigraphy of Ubiaja-1 Well*

The lithostratigraphy analysis result shows that there are nine lithofacies units delineated and they occur

at different intervals within the analyzed section. Details of the lithofacies units are given below.

ii. *Lithofacies unit 1: Conglomeratic sandtone*

This lighofacies unit occurs thinly between facies, it is whitish to pinkish in colour, grain size varies from fine to small pebbles, angular to rounded and poorly sorted. It has a thickness of 15 ft (600-615 ft); characterized by fining upward sequence and erosional base (unconformity) of a typical continental deposit. It is suggested to have been deposited by river system under high energy condition (Table 2).

iii. *Lithofacie Unit 2: Granulestone*

This lithofacies occurs at the uppermost part of the section with an interval range of 40-75 ft. The granulestone is reddish in colour, grain size ranges from medium to pebble; roundness varies from angular to rounded, and it is poorly sorted. The granulestone is friable and ferruginised in nature, it has a total thickness of 35ft.The facies shows fining upward sequence; unconformable relation with underlying facies typical of fluviatile deposit (Table 2).

iv. *Lithofacie unit 3: Pebbly sandstone*

The pebbly sandstone facies is whitish to pinkish in colour, grain size varies from fine to small pebbles, angular to rounded, poorly sorted in nature and more pebbly in content. It is suggested to have been deposited by high energy current in a continent environment associated with erosional base.

v. *Lithofacies Unit 4: Sandstone*

The sandstone occurs at different levels. Generally, they are whitish to reddish in colour at the upper part (75 to 110 ft). It is coarse grained and poorly sorted, whereas at the middle part of the section, the grain size is medium, moderately to poorly sorted. The lithofacies occurs at intervals 75 to 110 ft, 645 to 795ft, 815 to 845 ft, 855 to 865 ft, 915 to 930 ft. They are suggested to have been deposited in continental setting and unconformably overlying shale at the lower section of the studied interval (Table 2).

vi. *Lithofacies unit 5: Claystone*

The claystone facies is restricted to the upper part of well section. It varies in colour from light brown to white, sometimes ferrugenized. It varies in interval from 146 to 172 ft with total thickness 26ft. The presence of the whitish claystone (kaolinite) shows the extent of leaching and chemical transformation of double lattice clay into single lattice type.

vii. *Lithofacies unit 6: Mudstone*

The mudstone directly underlies the clay deposit in the upper part of section, though it also occurs at the lower part of the well section. It is reddish to greyish coloured facies which has add-mixture of clay and sand particles; varies from fine to small pebble. The mudstone facies occur at various intervals such as 172-390 ft, 960-1045 ft. it is suggested that the mudstone was deposited in a continental setting (Table 2). The grayish colour of the mudstone is indicative of carbonaceous content.

viii. *Lithfacies unit 7: Sandy Shale*

This lithofacies is light grey in colour and heterolith in nature, It is a light grey sandy shale which has sand/shale ratio (s/sh) = 45:55%, the sand size varies from fine to small pebble, fine to rounded and poorly sorted. It varies in interval from 890 to 900ft with a total thickness of 10ft, deposited in prograding deltaic environment.

ix. *Lithofacies unit 8: Shaley sand*

The shaley sand occurred at interval 850 to 870ft. It is a dark grey facies, heterolith in nature with sand/shale contents ratio (s/sh) = 55:45%. It is suggested to have been deposited within prograding deltaic system..

x. *Lithofacies 9: Shale*

This lithofacies is light grey to dark grey in colour, fissile and slightly ferrugenized. It occurs at various intervals 1000-1005 ft, 875-885 ft, 1020-1025 ft, 1370-1765 ft. It occupies smaller part of the section and it is suggested to have been deposited in anoxic marginal marine environment.

The lithogical sequence in the studied stratigraphic interval is not similar to other established stratigraphic sequence for Nkporo Shale (Edet and Nyong, 1984; Nwajide, 1990; Ola-Buraimo and Akaegbobi, 2013). It is strongly believed that the thick sandstone facies of Campanian to Early Maastrichtian age encountered in this studied stratigraphic section in the Ubiaja -1 well is a lateral extension of an intertongueing facies of Afikpo Sandstone from Afikpo Basin into Anambra Basin. The base of the Afikpo Sandstone in the well cannot be precisely placed but it is tentavely placed at 1165ft at the base of the interval where it first occurred in the available sample interval in the well section. It is characterized by fine to pebble sized particles, whitish to pinkish in colour, angular to rounded, moderately to poorly sorted at various intervals, fining upward sequence, and unconformably overlying the Nkporo Shale (Table 2).

A greater proportion of the Afikpo Sandstone is mainly sandy with some claystone and mudstone intercalations at the upper part of the interval, suggestive of deposition in continental environment. However, interval associated with intercalation of sand and shale or heterolith facies is indicative of prograding deltaic setting (see Table 2). The continental Afikpo Sandstone is unconformably overlying the marginal marine Nkporo Shale. The sandstone could serve as a good reservoir rock for the Nkporo shale source rock. Within the sandstone section is the intercalated shale which could serve as excellent seal or cap rock at the top (Table 2). The result reveals a new sandstone member in the Nkporo Formation or in another way

suggests Nkporo Formation to become Nkporo Group comprising of Nkporo Shale and Afikpo Sandstone.

Table 2: Lithostratigraphy, Palynological Zones and Paleoenvironment of the Studied Interval

Depth (Ft)	Litho-log	Description	Formation	Zone	Age	Paleo-environment
40		Granulestone	Afikpo Sandstone	*Foveotriletes margaritae* Assemblage Zone II	Early Maastrichtian	Continental To Deltaic
75		Coarse sandstone				
146		Claystone				
172		Mudstone				
		No Data				
		Mudstone				
555		Heterolith sand and shale				
600		Conglomeratic sandstone				
690		Coarse sandstone				
775		Pebbly sandstone				
780		Medium grained sandstone but pebbly in nature				
850		Shaly sand		*Milfordia spp* Acme Zone I	Campanian	
865		Sandstone				
870		Shaly sand				
885		Shale				
900		Sandy clay				
		Mudstone				
915		Sandstone				
960		Mudstone				
1165		Sandstone				
1370		NO DATA				
1425		Shale	**Nkporo Shale**			Marginal Marine

V. Biozonation

Palynological analysis was carried out yielded palynological contents such as pollen, spores, dinoflagellates , algae, and fungal spore. The interval yielded poor to moderate amount of palynomorphs which are fairly preserved. However, diagnostic forms present were used for palynozonation exercise. Two palynological zones were erected after the works of Jardine and Magloire, (1965); Lawal, (1982); Lawal and Moullade, (1986); Ola-Buraimo, (2012); Ola-Buraimo and Akaegbobi, (2013b). The details and basis of establishing the zones are given bellow.

Interval: 870-1425 ft

Zone: *Milfordia* spp. Acme Zone

Age: Campanian

Characteristics: The base of the interval is marked by the appearance of *Milfordia* sp., *Proxapertites cursus, Tricolpites* sp.*,* and *Inaperturopollenites* sp. Depth 1330 ft is characterized by the occurrence of *Milfordia* sp.*, Syncolporites marginatus* and *Tricolpites* sp. There is a continuous occurrence of *Milfordia* spp. in the interval with relative maximum development within the interval. Other forms that occurred within the interval include *Inaperturopollenites* sp, *Proxapertites cursus, Tricolpites* sp., *Syncolporites marginatus, Verrucatosporites usmensis, Zlivisporites blanensis, Milfordia jardinei, Cyathidites* sp. and *Laevigatosporites* sp. The top of the interval is marked by the top quantitative occurrence of *Milfordia* sp. The fossil assemblage observed here is similar to palynological report on *Milfordia* spp acme zone 3 reported on Tuma-1 well, Bornu Basin, Nigeria (Ola-Buraimo, 2012), also similar to assemblages reported on Nkporo Shale in Anambra Basin, southeastern Nigeria(Ola-Buraimo and Akaegbobi, 2013b). The interval is dated Campanian age and stratigraphically belongs to Nkporo Formation in Anambra Basin, southeastern Nigeria (see Tables 1 and 2).

Interval: 40-870 ft

Zone: *Foveotriletes margaritae* Assemblage Zone II

Age: Early Maastrichtian

Characteristics: The base of the interval coincides with the top of the underlying zone I marked by the quantitative top occurrence of *Milfordia* spp. The interval is sparse in miospores is characterized by the continuous occurrence of *Monocolpopollenites sphaeroidites* and occurrences of *Syncolporites* sp.*, Monosulcites* sp., *Ephedripites multicostatus, Milfordia* sp., *Milfordia jardinei, Laevigatosporites* sp.*,* and *Cyathidites* sp. The assemblage of palynomophs in this interval is comparable with other established zones. It is partly similar to earlier works of Ola-Buraimo, (2012) and Ola-Buraimo and Akaegbobi, (2013b). The interval is also dated Early Maastrichtian based on negative criteria: it lacks diagnostic Middle and Late Maastrichtian forms such as maximum development of Longapertites marginatus (Ogala *et al,* 2010), and appearance of Spinizonocolpites baculatus (Lawal and Moullade, 1986) respectively. It is also based on the stratigraphic position which suggests Early Maastrichtian age and well compared to the palynomorph assemblages reported on Tuma-1 well, Bornu Basin, northeastern Nigeria (Ola-Buraimo, 2012). Therefore, the interval is equivalent in terms of facies and age to Afikpo Sandstone established in Afikpo Basin (Nwajide, 1990; see Tables 1 and 2).

VI. Paleoenvironment of Deposition

The paleoenvironment of deposition of the sediments in the entire analyzed interval is characterized by continental to marginal marine The paleoenvironmental deduction made for this research work is based on the combined data of Non-Pollen Palynomorphs such as algae, fungi, microforaminiferal wall linings, gonyaulacacean/peridinacean ratio (G/P) after Harland (1983); and terrestrially derived pollens and spores.. The use of relative abundance of terrestrially derived pollen and marine derived dinoflagellate cysts have also been documented in the works of Lawal, (1982); Schrank, (1984); Edet and Nyong, (1992); Ojo and Akande, (2000); Ogala *et al,* (2009); Ola-Buraimo and Adeleye, (2010) and Ola-Buraimo and Akaegbobi (2013b).

The dinoflagellates that characterized this depositional system are peridinoid forms such as *Andalusiella polymorpha*, and *Andalusiella sp.* They are described to be dinocysts having relatively long processes. They are the only type of dinoflagellates that are present in the samples analyzed and they suggest deposition of the shale facie in the marginal marine environment.

The peridinoids which are the only form in abundance is attributed to relative low or reduced salinity as a result of admixture of fresh water (*Botryococcus braunii*) from the fluvial mixing with the saline water (dinoflagellate) of the marine environment present in the marginal marine setting. This similar view had been expressed by Upshaw (1964), Oloto (1987) and Ogala *et al (2009)*, Ola-Buraimo and Akaegbobi, (2013b).

VII. Conclusion

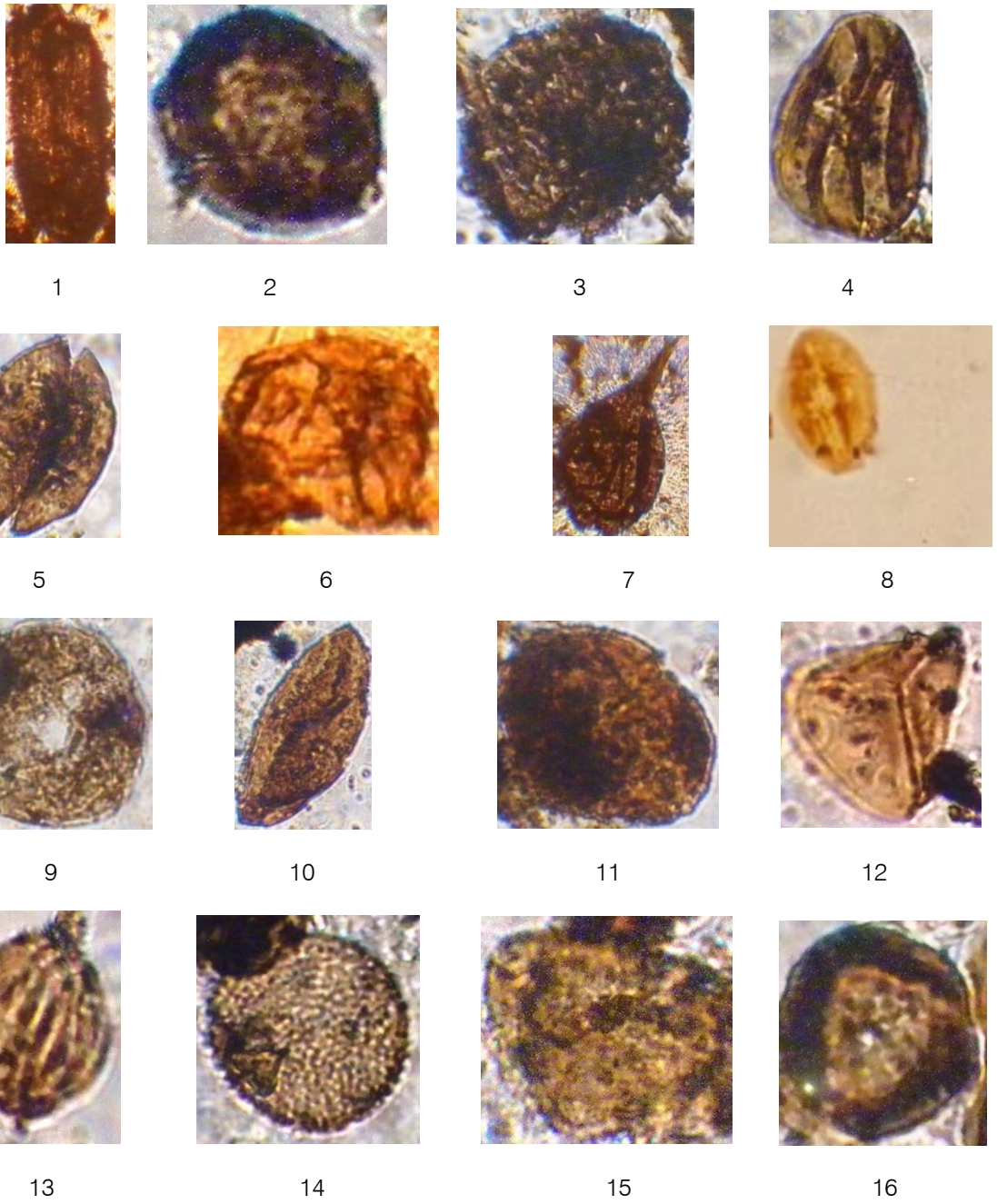
lithostatigraphy analysis revealed nine lithofacies units such as granulestone, coarse sandstone, pebbly sandstone, conglomeratic sandstone and medium grain sandstone characterized by medium to pebble sized grains, poorly sorted, erosional surfaces and fining upward signature, deposited in continental

environment under high energy current. Other facies include claystone and mudstone also deposited in continental environment. The heterolith facies such as sandy shale and shale sand were deposited in prograding deltaic system, while the dark grey shale was deposited in the marginal marine setting. The sandstone sequence is the Afikpo Sandstone unconformably overlying the Nkporo marginal marine shale.

Palynozones established indicated that the entire stratigraphic sequence belongs to Nkporo Shale/Afikpo Sandstone synonymous with Afikpo Basin but here established in Anambra Basin. This palynological revelation shows that there is lateral facies intertongueing of the Afikpo Sandstone in the Afikpo Basin into the Ubiaja- 1 well located in Delta State, Anambra Basin in Nigeria. The result reveals a new sandstone member in the Nkporo Formation or in another way makes Nkporo Formation to become Nkporo Group comprising of Nkporo Shale and Afikpo Sandstone. This further corroborates the complexity of Anambra Basin Stratigraphy and the need to further carry out investigations into the stratigraphy through the use of palynological tool and other useful tools.

Magnification ×800

PLATE I






17 18 19 20

Plate 1

1	*Ephedripites multicostatus*
2,3	*Milfordia* sp.
4	*Tricolpites* sp.
5	*Monocolpites* sp.
6	*Zlivisporites blanensis*
7	*Andalusiella* sp.
8	*Tricolporopollenites* sp.
9	*Milfordia jardinie*
10	*Monosulcites* sp.
11	*Monocolpopollenites sphaeroidites*
12	*Cythidites* sp.
13	*Ephedripites* sp.
14	*Proxapertites cursus*
15	*Syncolporites* sp.
16	*Milfordia* sp.
17	*Laevigatosporites* sp.
18	*Inaperturopolleinites* sp,
19	*Syncolporites marginatus*
20	*Verrucatospories* sp.

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Probability Distribution Functions (PDFs) Selection to Rainfall Time Series from Brazilian Semiaridcities

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Abstract- The Brazilian semiarid environment that has a rightly variable hydrologic behavior, and consequently is a climate change spot to all scenarios designed by IPCC. On this, the objective of this research was to verify the rainfall patterns and select the better distribution statistical adjustment inrainfall time series from semiarid of Pernambuco State, in a total of thirty analyzed cities, inside the Brazilian semiarid. Therefore, through the analysis of rainfall distribution in monthly and annual time series, the Probability Distribution Function (PDF), that had produced the better adjustment for the data set observed for most of cities was the Weibull (type 3) for the monthly data set, while in the annual time series the distribution that obtained the best adjustment to the data among those observed was the Logistics PDF, better adjusted to ten cities. The distribution Gama (type 2) Probability Distribution Function was better adjusted to six cities, and the GEV (Generalized Extreme Values) distribution showed good adherence in five of the thirty analyzed cities. The Log-Normal distribution adjusted well to four cities, the Fréchet distribution (Fisher -Tippett type 2) to three cities, and Weibull distribution (type 3) and Normal adjusted well just to one city each.

Keywords: *climate variability, rainfall time series, seasonal rainfall variability.*

GJSFR-H Classification: *FOR Code: 050299*

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I. Introduction

Climate change and its impacts on human society and ecosystems have received considerable attention from scientists, the public and governments around the world (Milly et al., 2008). The necessity for a better understanding of the consequences of climate change on water resources has been the greatest challenge in water planning and management, especially in arid and semi-arid regions, dependent on climate variability, mainly rainfall distribution (Zhaoet al. , 2013).

Although climate changes occur on a global scale its impacts often vary from region to region (Trajkovic; Kolakovic, 2009). Therefore, the analysis of statistical variations in the meteorological variables of rainfall, as well as of temperature, represent important tasks in detection of climate changes on regional scale (Gocic and Trajkovic, 2013). In this perspective the semiarid region of Brazil hasthe variability as feature of yourrainfall pattern, with intense rains concentrated in short periods of time (12 mm min^{-1}), in addition to a large variation of rainfall recurrence, irregular spatial and temporal occurrence of their rains (Cantalice et al., 2013).

Rainfall variability is an important feature of semiarid climates, and climate change is likely to increase this variability in many of these regions around the world (Batisaniand Yarnal, 2010). In this sense, Ramos and Martinez-Casasnovas (2006) add that semiarid climates exhibit complex patterns of spatial and seasonal variability of rainfall, accentuated by the unpredictability of rainfall year by year, within the year and even during a single rainfall.

The analysis of frequency distribution of rainfall provides subsidies for water planning, mainly in determining critical periods prevailing in a certain region, be them drought events, as well as floods, the knowledge of rainfall distribution behavior provides us with information that aims to reduce the consequences caused by rainfall variability (Silva et al., 2013).

In several future scenarios of climate change, mainly due to the increase in greenhouse gases concentrations in the atmosphere, it's often assumed that only the average can change, with the standard deviation remaining unchanged (Ben-Gai et al., 1998). However been demonstrated by Mearns et al. (1984), Katz (1991), and Katz and Brown (1992), that the relative frequency of extreme events depends on changes in standard deviation and not just of the average. Katz (1991) assumes that a change in a climate variable that has a probability distribution will also result in a change in the form of that distribution.

The idea of using probability distributions as a statistical paradigm in climate change studies was previously suggested by Katz (1991) that emphasizes; consequently, a climate change may involve a combination of two statistical results: a change of extreme event location combined with a change in the scale of the distribution function.

In this sense, said Naghettini and Portela (2012), that although the great difference between cities

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in relation to a better adjustment of probability distribution in the monthly and annual rainfall data, all the models found they're part the set of probabilistic models for continuous random variables, with probability density functions and probability distribution, defined by parameters, these being commonly applied to hydrological variables.

According Mamoon and Rahman (2017), many studies have been developed involving probability distribution adjustments or probability estimation, using the Probability Distribution Functions in climatic variables analysis, and is emphasized that the benefits in planning activities that minimize climatic risks. Therefore, Sharma and Singh (2010) said that the selection of a probability distribution that gives the best adjustment to rainfall data is an important research topic in the field of statistical hydrology. The best use of water resources from rainfall requires adequate knowledge of the behavior of the rainfall regime, mainly in relation to the probability of occurrence of rainfall, as well as the use of Probability Distributions Functions in water planning (Catalunha et al., 2002; Silva et al., 2013).

However, Khudri and Sadia (2013), warns that the distribution adjustment is a procedure of selecting a statistical distribution that best suits a set of data generated by some random processes, and the distribution of probability is an important instrument to deal with uncertainty; however, the wrong selection of the statistical distribution results in a wrong planning.

Thus, the objective of this research was to select the statistical distribution that can better adjust to rainfall data and express the rains data distribution pattern of the Brazilian semiarid cities under climatic change risk.

II. Materials and Methods

a) Study area

The thirty cities this study were selected of Brazilian Pernambuco State that are inserted in the Brazilian semiarid,in the Northeast of Brazil(Figure 1 and 2), which is characterized by an irregular (space/time) rainfall regime, low rainfall index, with average annual rainfall of 800 mm or less, average annual temperatures ranging from 23 to 30 C°, average insolation of 2,800 h year^{-1}, and the predominant climate of the semiarid are of the Pernambuco State is classified as being of the hot dry type or BSh of Köppen (Alvares, 2014).

b) Rainfall time series

The time series rainfall data used are part of the SUDENE (1990) database, Water and Climate Pernambuco Agency (APAC) database; National Water Agency (ANA); Agronomic Institute of Pernambuco (IPA); National Department of Works Against Drought (DNOCS); Company of Technical Assistance and Rural Extension of the State of Pernambuco (EMATER-PE); Mineral Resources Research Company (CPRM) and San Francisco Hydroelectric Company (CHESF), compiled and made available from the Hidroweb of the National Water Agency (ANA) website.

The rainfall time series analyzed had different periods, where the selection criterion was a minimum data record of 30 years, as shown in table 1, which is the standard for the statistical description in terms of average and variability of the climatic elements, as recommended by the World Meteorological Organization (WMO), specialized agency of the United Nations for meteorology.

c) Distribution Adjustment

i. *Kolmogorov-Smirnov test*

The Kolmogorov-Smirnov test, was applied to verify the adherence or distribution adjustment, to the rainfall data of the cities under climatic change risk, at the 5% significance level, in order to determine which probability distribution model best adhered to the distribution of the dataset of each rainfall time series. The Kolmogorov-Smirnov test compares an empirical distribution function with an observed distribution function, and the test is based on the empirical cumulative distribution function (CDF), which is given by:

$$F_n(x) = \frac{1}{n} \times [\text{Number of observations } \leq x]$$

The statistic of the Kolmogorov-Smirnov test (D) is given by the largest vertical difference between the functions of cumulative distribution theoretical and empirical:

$$D = \max_{1 \leq i \leq n} \left(F_{(x_i)} - \frac{i-1}{n}, \frac{i}{n} - F_{(x_i)} \right)$$

The adjustment adherence test essentially evaluates the compatibility of random samples of the assumed theoretical probability distribution, when the null hypothesis - H0: data of the variable in question follows a given distribution, while the alternative hypothesis - H1: data of the variable in question don't follow any known distribution, or the assumed distribution (when the intention is to evaluate the adjustment or not to a predetermined distribution). In the application of the adherence test or distribution adjustment, we can accept the null hypothesis H0 if the observed test statistic (p-value) exceeds the critical value of the stipulated level of significance.

III. Results and Discussion

a) Rainfall regime from some Brazilian semiarid cities under climatic change risk

The table 4 show the monthly and annual average rainfall to time series of the 30 selected cities. The monthly rains were concentrated within 3 to 5 months of year, sometimes beginning in December, but

mainly the monthly rains had occurred between January and April, and occurring weak rains in May.

The Arcoverde and Triunfo cities showed a monthly rainfall quite different due to the rains both are impacted by orography, Arcoverde and Triunfo has respectively, altitude of 663m and 1010m, as well this cities are on a climatic transition zone that coincides with boundaries between watersheds. The drought period occurs between June and December, however, nine cities had showed monthly rainfall less than 30 mm in May.

Also was observed annual rainfall average of 845.8 mm in Ipubi city to 55 years of records, and 400.2 mm in 82 years records in Petrolandia City, showing high space and temporal variability, even these cities are 372 km from each other. Rocha (2009) and Moura et al (2009) had reported an annual rainfall average among 200 and 800 mm to all Brazilian semiarid. In addition another factor that we must take into account is the time series size can influences in these rainfall average values.

The inter-annual or seasonal variability characteristic of precipitation in the Northeastern semi-arid region is associated with variations of the Sea Surface Temperature patterns over the tropical oceans, affecting the position and intensity of the Intertropical Convergence Zone on the Atlantic Ocean, which contributes to the occurrence or not of rainfall in the region (Hastenrath, 1984; Moura and Shukla, 1981), thus, the occurrence of low total annual rainfall values during the rainy season (December-May) is closely related to interannual variability in rainfall records.

In specific studies on climate in the northeastern semi-arid developed by NAE (2005), Kayano and Andreoli (2009), Marengo et al. (2011) discussed important aspects of the water regime and the vulnerability of this region to extremes of climatic variability, where the authors reiterate that the occurrence of periods like a "small summers" in the rainy season, that depending on intensity and duration, can cause serious damage to agriculture local.

The time series records confirmed this inter annual variability of the rainfall; in addition, a high intra seasonal variability in the rainfall regime can be observed through the standard deviation (σ) in the table 2, where were observed values higher than the time series average for some months, whether in rainy season or the dry season. According to Kayano and Andreoli (2009), the Brazilian semiarid is the one with the highest intra-seasonal variability in South America.

b) Distribution of Probability of monthly and annual rainfall time series

The table 3 show the best Probability distribution functions best adjusted to the monthly and annual rainfall time series of the analyzed cities. Observing the results, there was a predominance of a better fit for the Weibull distribution (type 3) in the rainy season (December - May), rarely the same distribution was also found in some cities during the dry season in the region, however, in most cases during the dry season the data didn't adjusted for any of the Probability distribution functions tested.

The difficult to adjust Probability distribution functions in dry seasons from arid and semiarid environments, according to Haddad and Rahman (2011) said, that the selection of the best distribution adjustment is not an easy task as there are many possible distributions that could be used. In addition, there are many estimation methods of available parameter that could be applied to the selected probability distribution.

Still in the Brazilian semiarid, Silva et al. (2013)analyzing the probability distribution in rainfall time series of 76 years (1913 - 1989) had observeda great monthly and annual diversification of functions that had adjusted to the rainfall data. There was to Ceara State a predominance of adjust to the Gumbel distribution in 90% to the Cities in April and 50% in January, and also, the Weibull distribution was well adjusted in 60% of the stations for February and 50% of the stations in May. The Weibull Probability distribution functions was the unique that showed good adherence in all the months of the rainy period of that region (January - May).This findings are quite different of the results to present study of the Pernambuco State.

From results is possible conclude and agree toCataluñaet al. (2002)and Silva et al.(2013), that the use of probability distributions functions is directly related to the nature of the data to which the function relates, that is, some have good estimation capacity for a small number of data, while others need a larger time series.

In a study developed in Qatar, Mamoon and Rahman (2017) selected best adjustment of probability distributions for historical rainfall series data ranging from 24 to 49 years in 29 climatic stations, with an average annual rainfall of 77.9 mm, with an average number of rainy days of only 13 days, corresponding to the typical interval for the arid region (between 10 and 50 rainy days), and like reported by Noy-Meir (1973), 14 different types of probability distributions were tested under three adjustment and adherence tests: Kolmogorov-Smirnov, Anderson-Darling and Chi-square. The authors verified that there is no a single distribution that to adjust the annual rainfall data, but the GEV (Generalized Extreme Values) distribution obtained the best performance among the other distributions in the adjustment for that country, with a 72% of observations.

The figure 3 show the best fits between Probability Distributions Functions (PDFs) for annual rainfall of the studies cities from Brazilian semiarid. The GEV distribution obtained good adherence in 5 of the 30

analyzed cities: Floresta, Inaja, Parnamirim, Petrolandia and Salgueiro.The Logistic PDF was better fitto 10 cities, while the distribution Gama (type 2) to 6 cities, other distributions found were Log-Normal distribution to 4 cities, Fréchet distribution (Fisher-Tippett type 2) in 3 cities, and Weibull and Normal distribution just to one city each.

To similar analysis of fits between Probability Distributions Functions (PDFs) and rainfall distribution to 28 cities of Pernambuco State from Brazilian semiarid between 1963 and 1991 (28 years), Souza et al. (2010) using six probability distributions: Normal, Exponential, Log-Normal, Beta, Gamma and Weibull, using the Chi-square test, observed that the Normal and Exponential distribution were unable to model any of the months under study, the Log-Normal distribution was adequate for the Julyrains, August, September and October (drought period); the Gama distribution did not adjust to the February and March rains, and again, the Weibull distribution obtained good adherence to February and March rains, but did not adjust to the month of February. However, the Beta distribution adjusted well to all months of the year, these results reinforce the idea that there is no single distribution that adjust the monthly or annual rainfall data.

Sanches and Aparicio (2017) in the Spanish semiarid observed the best adjust between the Wakeby Probability distribution function and monthly maximum, seasonal maximum, and annual maximum. In a Chilean semiarid snow-glacier fed watershed, Balocchi et al. (2017) again had used the Gumbel and Goodrich probability distribution functions, and againthe Log-Normal Probability Density Function (PDF) was better adjusted to the precipitation and streamflowbehavior on this watershed.

IV. Conclusions

The selection of the Probability Distributions Functions (PDF) best adjusted to the monthly and annual rainfall data from 30 Brazilian semiarid cities confirmed the high spatial-temporal variability of these events according to the time series used for each city, with a monthly predominance of a better adjustment for the Weibull distribution (type 3) in the rainy season.

While in the annual time series, the distribution that obtained the best adherence to the data among those observed, was the Logistics distribution, obtaining a better adjustment in 10 cities, the distribution Gama (type 2) 6 cities, GEV distribution (Generalized of Extreme Values) (4 cities), Fréchet distribution (Fisher-Tippett type 2) in 3 cities, Weibull distribution (type 3) and Normal distribution, in 1 city each.

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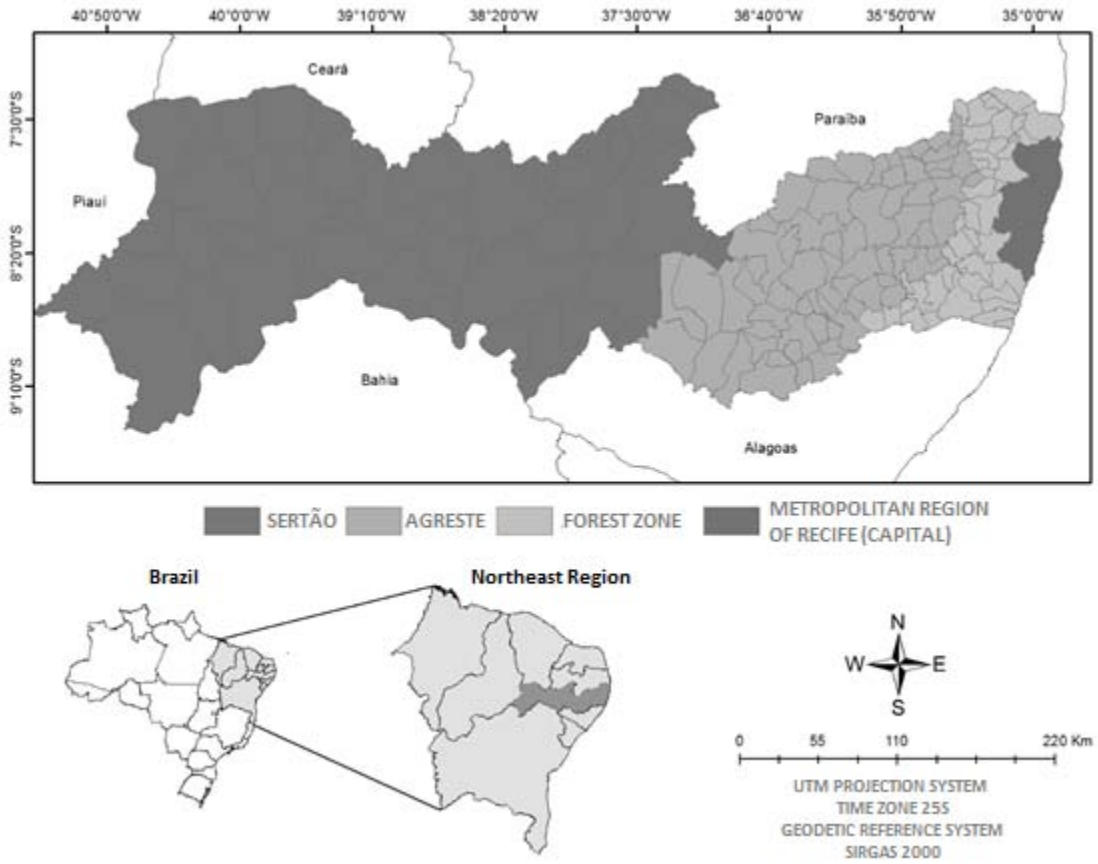


Figure 1: Geographic location of Pernambuco State

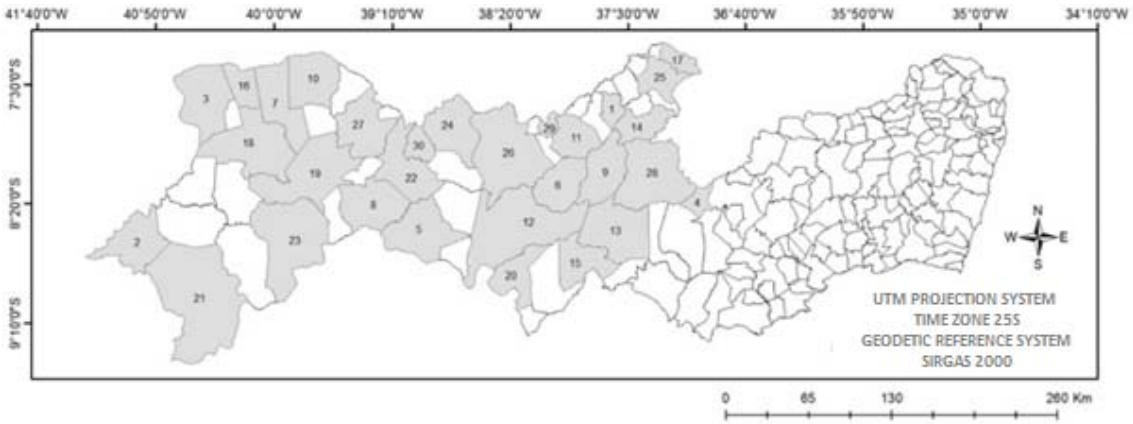
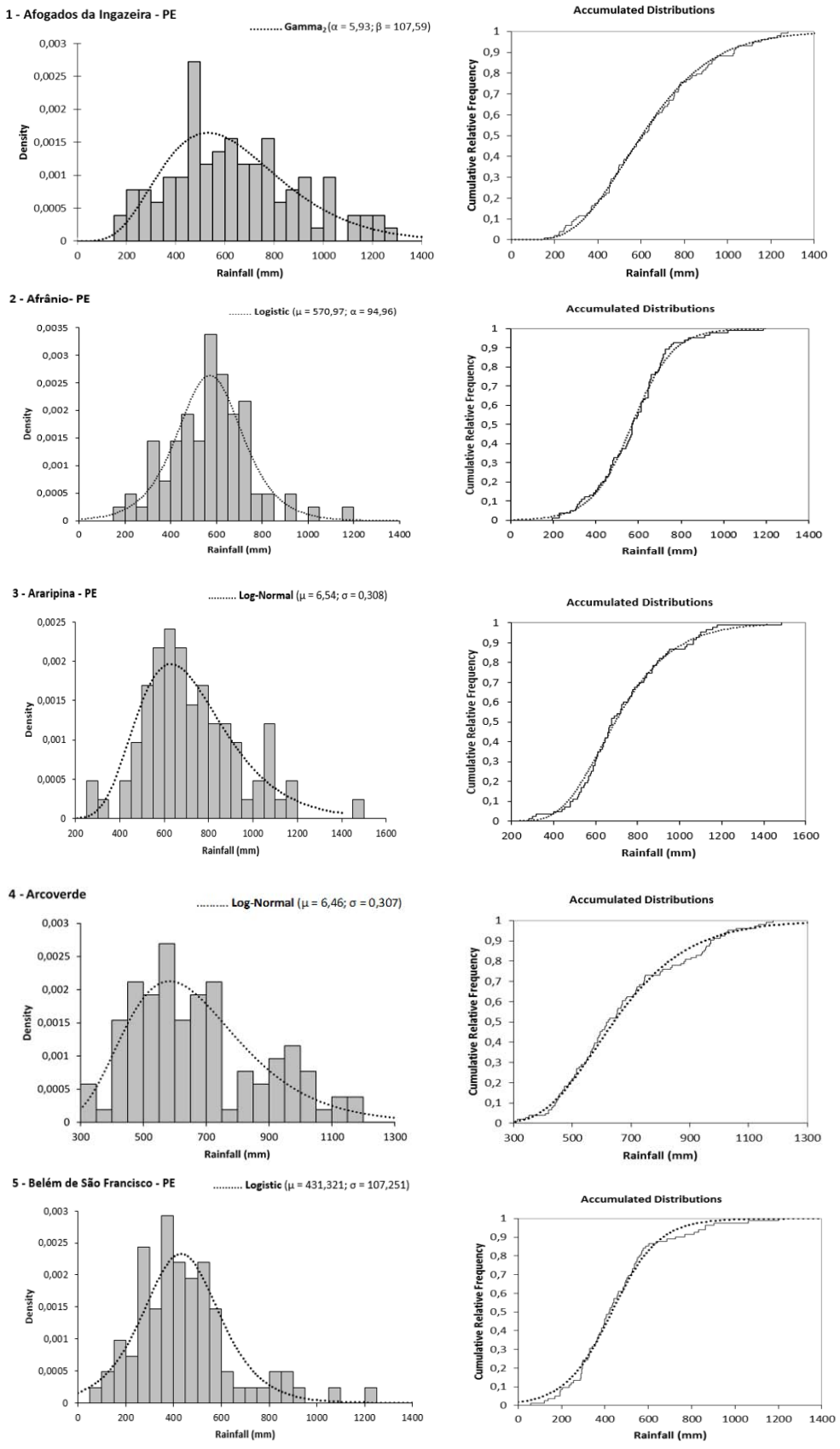


Figure 2: Geographic location of the Sertão Region of Pernambuco State and analyzed cities



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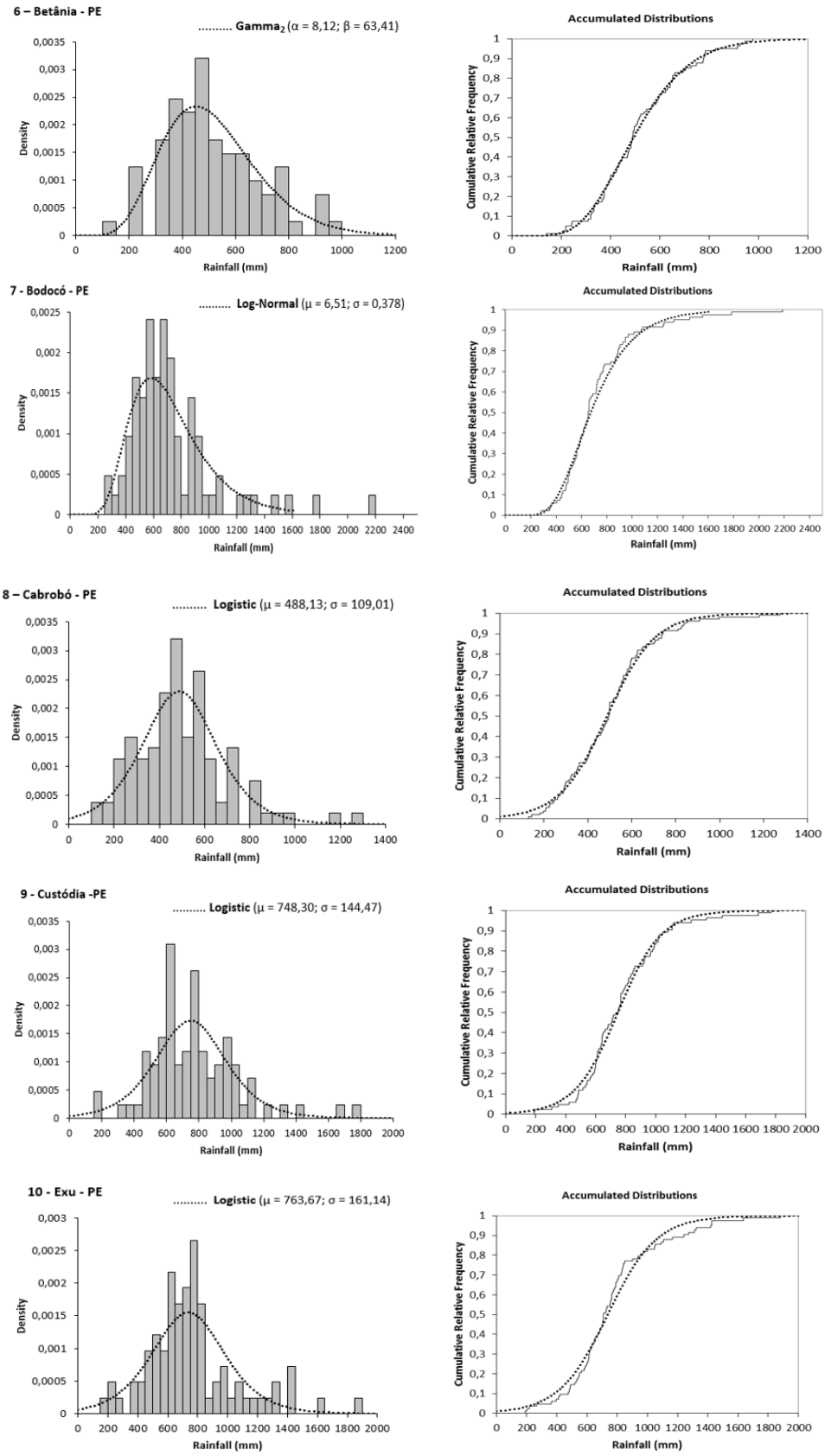

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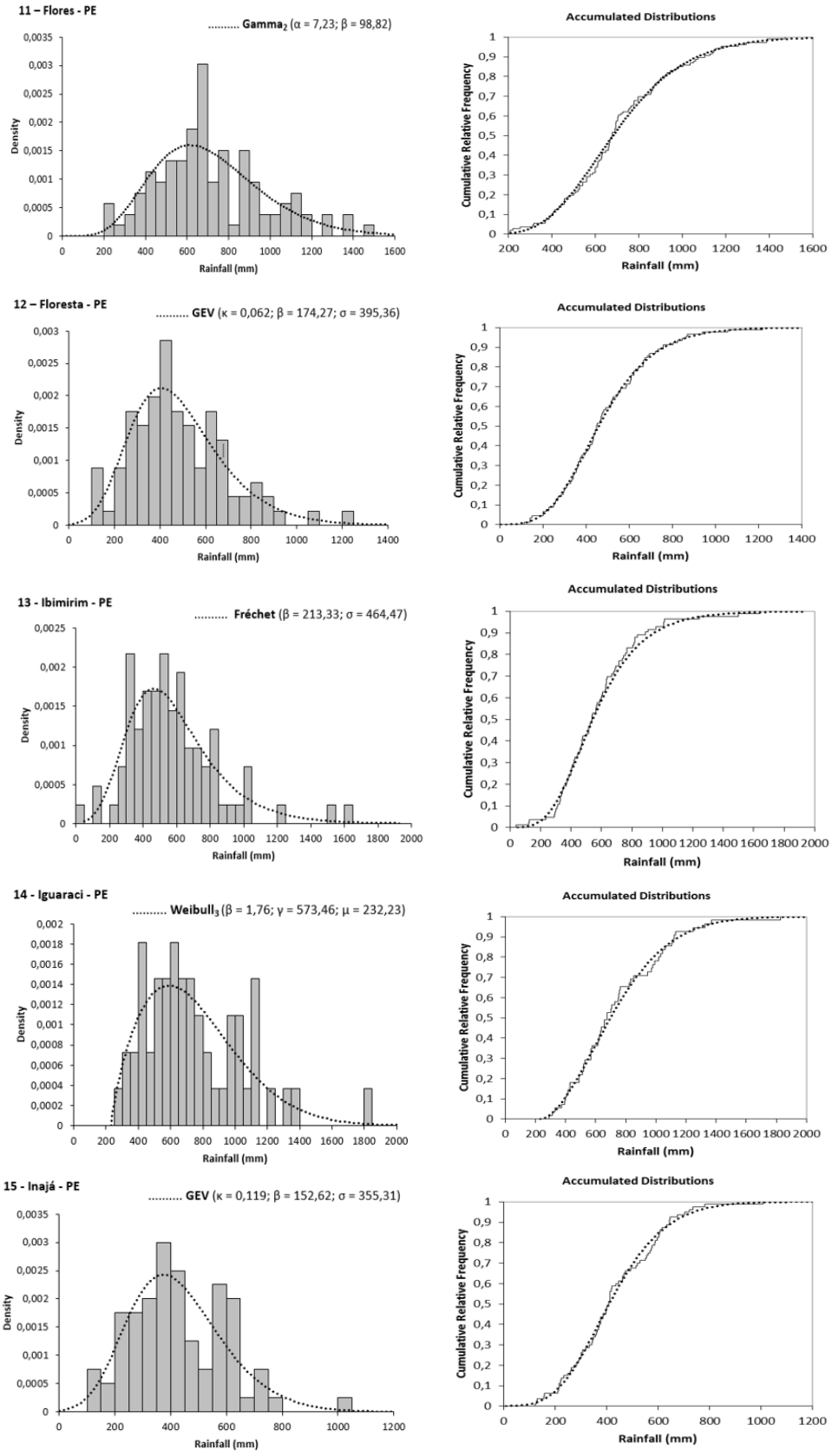

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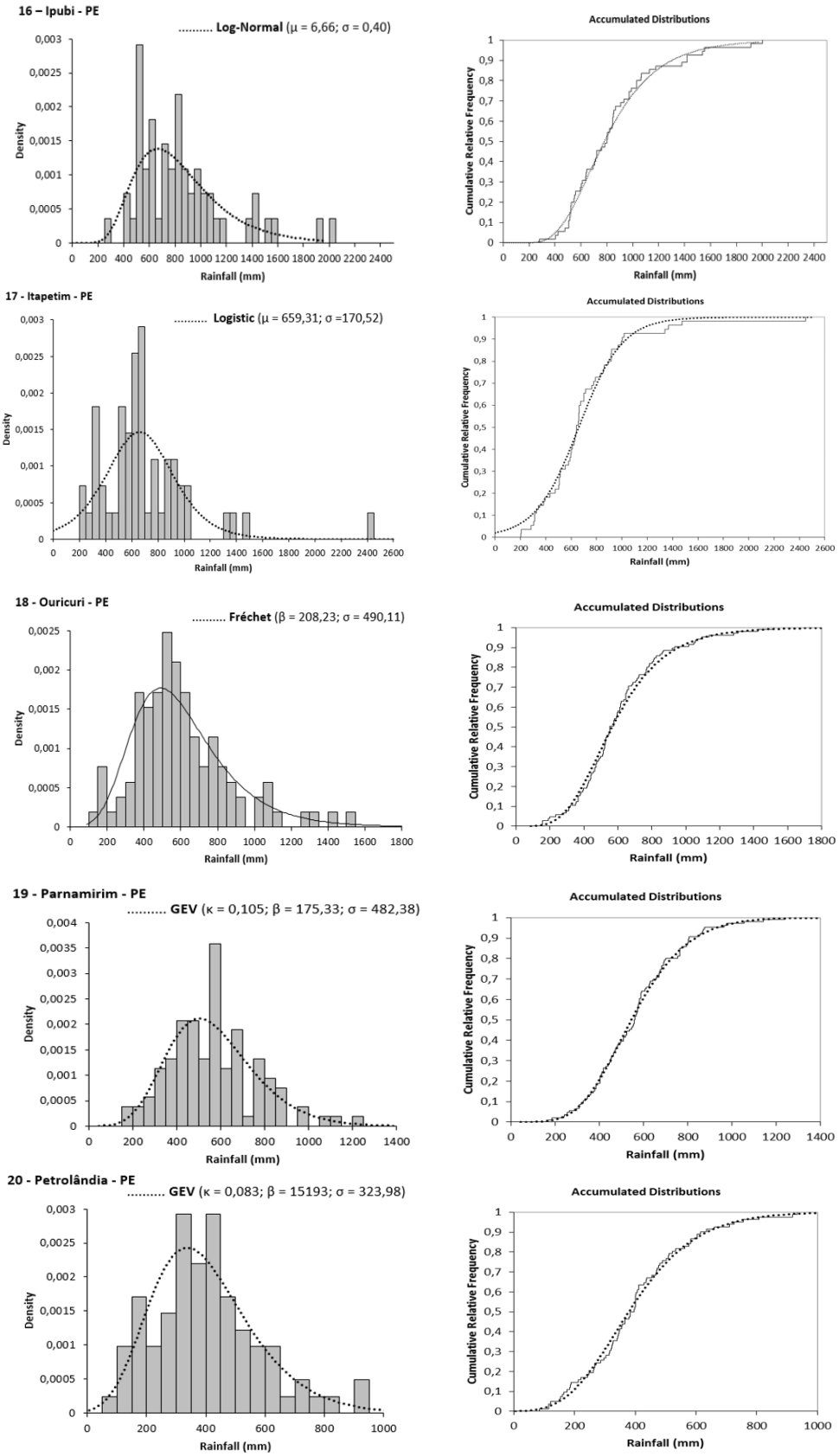

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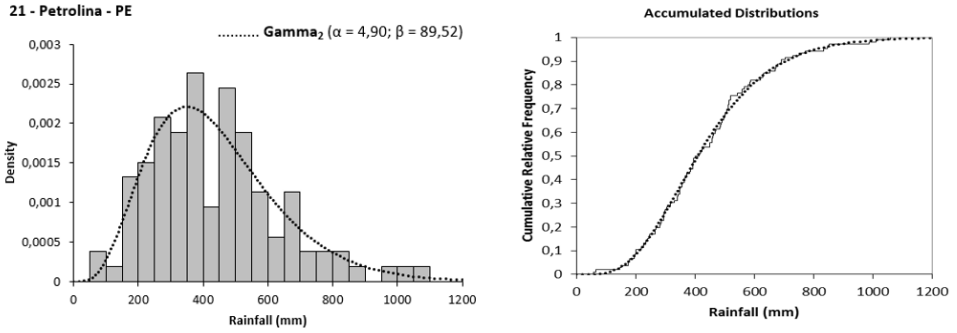

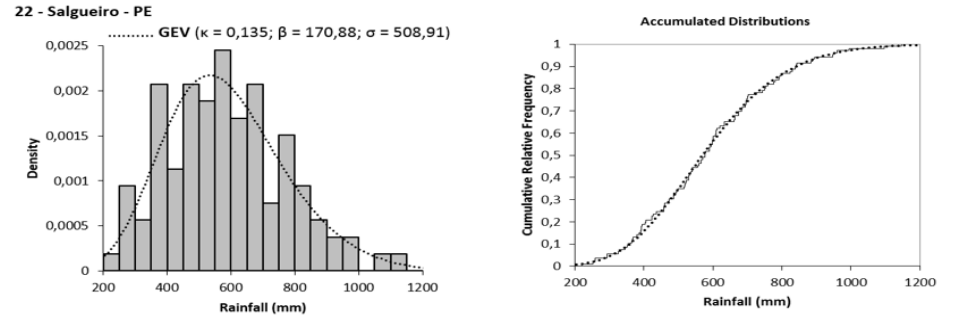

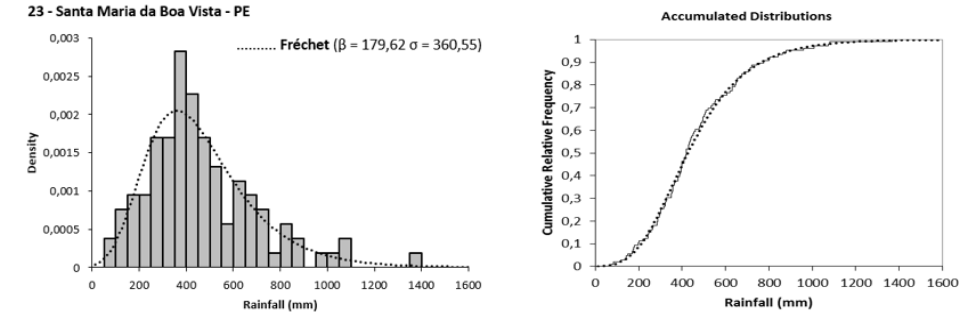

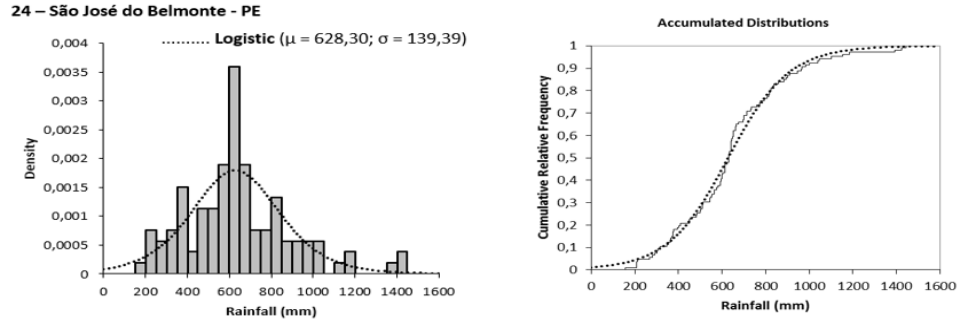

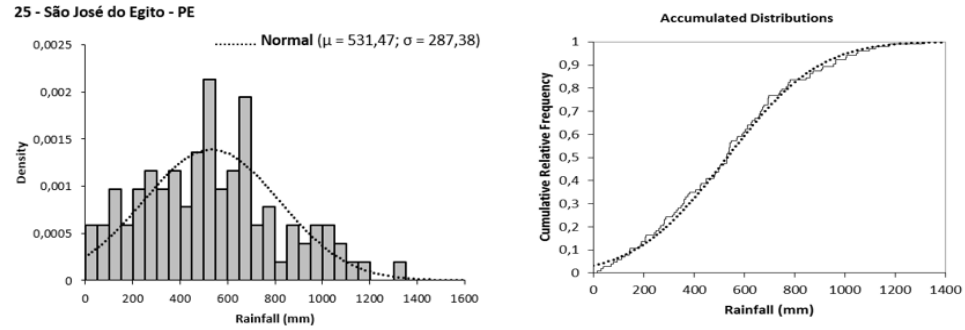

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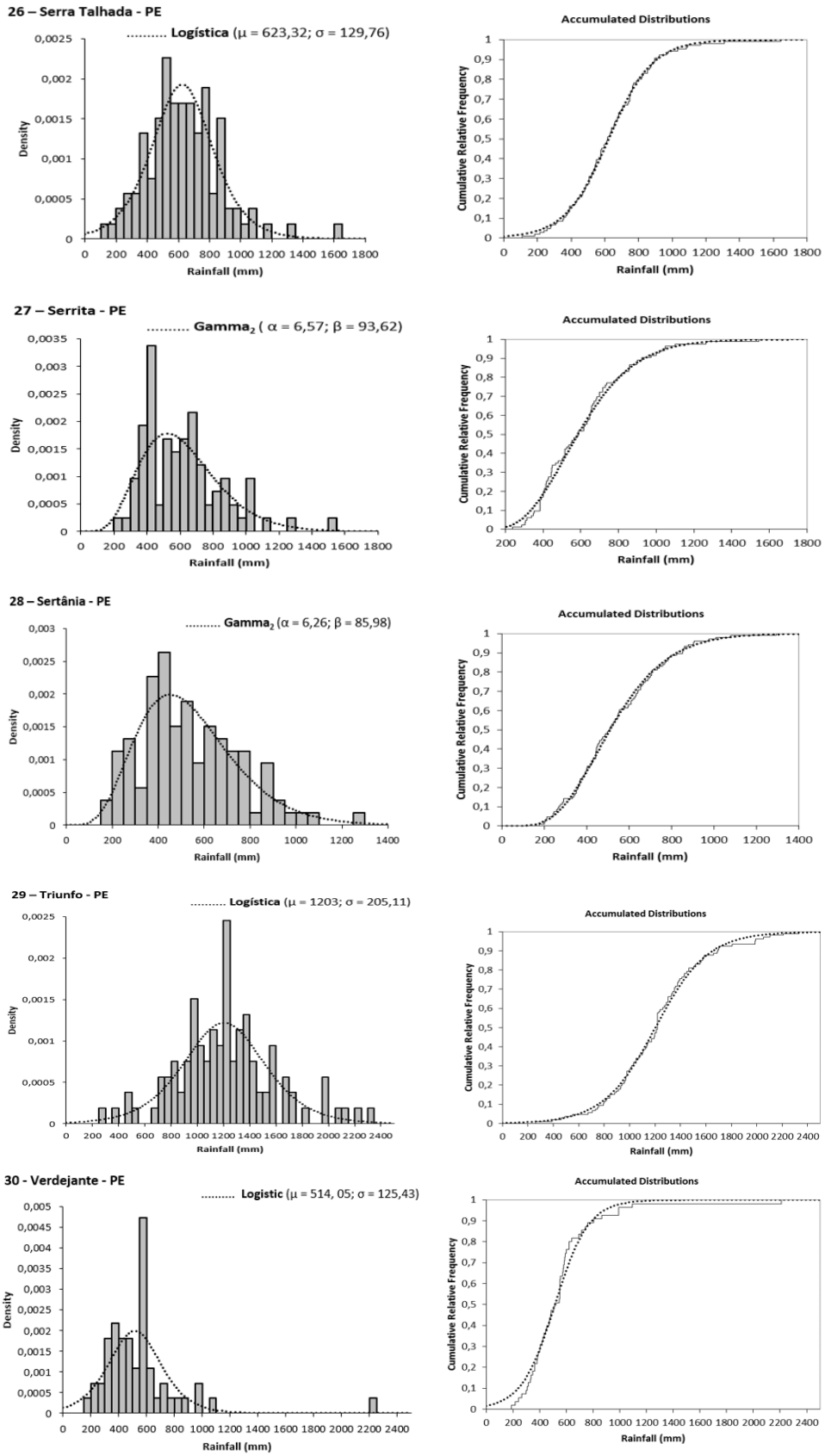

Figure 3: Probability Density Function (PDF) (left) and Accumulated Distribution Function (ADF) (right) that best adjusted for annual rainfall data of analyzed cities

Table 1: Geographic characteristics of stations sites analyzed (Rainfall)

Station Code		Station	Latitude (S)	Longitude (W)	Altitude (m)	Period (Nº of years)
00737023	1	**Afogados da Ingazeira-PE**	07°44'	37°38'	525	1914-2016 (103)
00841015	2	**Afrânio-PE**	08°29'	41°00	530	1934-2016 (83)
00740014	3	**Araripina-PE**	07°33'	40°34'	620	1934-2016 (83)
00837005	4	**Arcoverde-PE**	08°26'	37°04'	663	1913-2016 (104)
00838004	5	**Belém de São Francisco-PE**	08°45'	38°57'	305	1935-2016 (82)
00838005	6	**Betânia-PE**	08°17'	38°02'	431	1936-2016 (81)
00739021	7	**Bodocó-PE**	07°48'	39°56'	440	1934-2016 (83)
00839002	8	**Cabrobó-PE**	08°30'	39°19'	350	1911-2016 (106)
00837011	9	**Custódia -PE**	08°06'	37°39'	542	1933-2016 (84)
00739023	10	**Exu-PE**	07°31'	39°43'	510	1934-2016 (83)
00737027	11	**Flores-PE**	07°52'	37°58'	460	1911-2016 (106)
00838000	12	**Floresta-PE**	08°32'	38°11'	361	1926-2016 (91)
00837025	13	**IbimirimPE**	08°23'	37°38'	445	1934-2016 (83)
00737030	14	**Iguaraci-PE**	07°55'	37°31'	585	1962-2016 (55)
00837038	15	**Inajá-PE**	08°55'	37°49'	355	1937-2016 (80)
00740018	16	**Ipubi-PE**	07°39'	40°08'	560	1962-2016 (55)
00737031	17	**Itapetim-PE**	07°22'	37°11'	630	1962-2016 (55)
00740021	18	**Ouricuri-PE**	07°53'	40°04'	432	1912-2016 (105)
00839013	19	**Parnamirim-PE**	08°05'	39°34'	379	1911-2016 (106)
00938000	20	**Petrolândia-PE**	09°04'	38°18'	282	1935-2016 (82)
00940006	21	**Petrolina-PE**	09°23'	40°30'	376	1911-2016 (106)
00839016	22	**Salgueiro-PE**	08°04'	39°07'	415	1911-2016 (106)
00839018	23	**Santa Maria da Boa Vista-PE**	08°48'	39°50'	452	1911-2016 (106)
00738029	24	**São José do Belmonte-PE**	07°52'	38°47'	460	1911-2016 (106)
00737036	25	**São José do Egito-PE**	07°28'	37°17'	575	1914-2016 (103)
00738030	26	**Serra Talhada-PE**	07°59'	38°18'	435	1911-2016 (106)
00739026	27	**Serrita-PE**	07°49'	39°29'	440	1934-2016 (83)
00837033	28	**Sertânia-PE**	08°05'	37°16'	605	1911-2016 (106)
00738032	29	**Triunfo-PE**	07°50'	38°07'	1010	1911-2016 (106)
00738036	30	**Verdejante-PE**	07°55'	38°59'	455	1962-2016 (55)

Table 2: Monthly and Annual Rainfall Average (mm) and Standard Deviation (σ) of the Time Series of Analyzed cities

	Station	January	February	March	April	May	June	July	August	September	October	November	December	ANNUAL
1	Afogados da Ingazeira-PE	68,0 ± 75,5	101,7 ± 74,1	150,0 ± 105,1	121,7 ± 84,7	66,4 ± 63,5	36,1 ± 33,6	26,0 ± 28,0	9,8 ± 18,9	4,6 ± 10,5	10,2 ± 21,6	13,0 ± 22,5	30,4 ± 42,4	638,0 ± 262,0
2	Afrânio-PE	90,2 ± 95,5	84,5 ± 53,5	110,3 ± 71,6	75,2 ± 61,7	22,2 ± 17,0	10,5 ± 7,0	6,1 ± 4,7	4,8 ± 2,9	15,0 ± 9,8	35,5 ± 24,1	52,3 ± 42,9	66,0 ± 52,0	572,5 ± 174,4
3	Araripina-PE	116,3 ± 56,4	120,2 ± 51,4	170,2 ± 73,3	88,0 ± 63,8	37,4 ± 62,4	17,8 ± 47,9	12,0 ± 51,3	7,2 ± 29,7	9,9 ± 15,1	20,2 ± 20,6	47,9 ± 26,1	77,8 ± 39,7	724,8 ± 218,6
4	Arcoverde-PE	50,4 ± 56,4	61,5 ± 51,4	95,9 ± 73,3	86,8 ± 63,8	86,2 ± 62,4	72,2 ± 47,9	71,4 ± 51,6	37,9 ± 29,7	18,4 ± 15,0	24,2 ± 20,6	28,2 ± 26,1	38,4 ± 39,7	671,4 ± 207,4
5	Belém de São Francisco-PE	76,4 ± 98,6	65,4 ± 66,5	104,6 ± 91,0	58,5 ± 59,5	25,6 ± 36,1	11,6 ± 12,5	9,4 ± 9,1	3,5 ± 7,2	3,2 ± 6,9	7,1 ± 13,6	37,6 ± 56,1	47,7 ± 53,4	450,4 ± 204,8
6	Betânia-PE	67,8 ± 64,4	74,3 ± 59,9	122,9 ± 85,6	79,3 ± 60,2	40,2 ± 37,7	23,1 ± 24,6	17,9 ± 20,4	5,4 ± 7,5	7,1 ± 11,0	10,4 ± 16,6	23,1 ± 31,3	43,1 ± 44,4	514,6 ± 180,6
7	Bodocó-PE	115,4 ± 114,6	117,8 ± 109,9	146,4 ± 89,5	115,7 ± 112,6	46,2 ± 55,5	13,3 ± 11,5	12,6 ± 13,9	3,7 ± 6,6	4,8 ± 10,0	21,0 ± 27,2	48,3 ± 58,6	80,6 ± 84,2	725,8 ± 317,9
8	Cabrobó-PE	69,9 ± 64,1	82,2 ± 75,1	112,6 ± 82,3	72,2 ± 64,0	28,1 ± 31,6	14,1 ± 14,9	9,0 ± 10,9	3,1 ± 4,3	4,1 ± 11,2	10,4 ± 15,8	39,2 ± 40,7	55,8 ± 67,2	500,6 ± 202,8
9	Custódia -PE	73,7 ± 72,8	105,9 ± 74,7	168,2 ± 138,2	132,0 ± 87,4	85,7 ± 69,8	58,0 ± 46,0	39,9 ± 38,5	16,6 ± 17,7	13,8 ± 19,1	13,9 ± 21,8	27,4 ± 33,0	34,6 ± 34,0	769,6 ± 275,9
10	Exu-PE	104,5 ± 82,1	122,0 ± 91,6	159,9 ± 88,4	106,0 ± 90,5	74,0 ± 71,5	33,3 ± 31,5	25,3 ± 34,0	12,0 ± 20,1	7,3 ± 15,3	21,5 ± 38,3	40,6 ± 49,4	61,1 ± 55,6	767,7 ± 310,3
11	Flores-PE	82,7 ± 75,1	115,4 ± 82,2	163,2 ± 105,4	126,9 ± 82,7	69,0 ± 56,0	35,3 ± 37,7	25,6 ± 27,7	9,7 ± 14,4	8,2 ± 14,5	14,4 ± 25,6	26,4 ± 36,4	37,6 ± 43,8	714,4 ± 265,7
12	Floresta-PE	67,5 ± 74,8	83,9 ± 76,6	120,0 ± 94,5	67,0 ± 61,0	25,9 ± 23,9	17,8 ± 21,2	12,5 ± 13,2	3,9 ± 4,8	5,4 ± 10,9	9,2 ± 17,6	21,4 ± 28,7	51,5 ± 60,1	486,0 ± 208,8
13	Ibimirim-PE	54,2 ± 64,5	76,8 ± 66,7	128,7 ± 109,5	100,8 ± 103,8	61,2 ± 58,4	37,9 ± 44,6	27,9 ± 34,5	11,4 ± 21,7	5,7 ± 11,8	11,3 ± 21,0	21,7 ± 27,6	38,8 ± 42,7	576,5 ± 270,3
14	Iguaraci-PE	78,6 ± 79,0	100,9 ± 73,4	164,7 ± 116,7	139,4 ± 107,1	75,5 ± 59,4	46,9 ± 32,3	32,2 ± 31,0	15,7 ± 24,8	11,2 ± 14,6	13,5 ± 20,6	22,5 ± 25,1	41,9 ± 48,3	743,1 ± 310,5
15	Inajá-PE	52,6 ± 55,6	49,9 ± 50,5	82,7 ± 75,8	50,0 ± 49,0	35,0 ± 33,5	31,7 ± 24,4	32,5 ± 23,0	15,1 ± 14,1	8,7 ± 12,4	9,1 ± 14,4	22,2 ± 25,6	37,9 ± 51,1	427,4 ± 172,2
16	Ipubi-PE	128,7 ± 106,2	135,0 ± 109,7	194,2 ± 142,7	116,8 ± 124,7	54,1 ± 55,8	30,6 ± 36,5	21,6 ± 26,0	6,5 ± 9,6	11,7 ± 19,6	17,2 ± 19,1	49,6 ± 43,5	79,7 ± 66,7	845,8 ± 362,3
17	Itapetim-PE	81,8 ± 70,9	114,8 ± 148,1	143,7 ± 95,2	137,0 ± 125,4	68,4 ± 68,8	41,1 ± 36,5	29,7 ± 24,9	12,9 ± 19,8	5,9 ± 9,6	16,8 ± 29,1	12,2 ± 17,0	34,8 ± 39,2	698,9 ± 363,1
18	Ouricuri-PE	91,9 ± 80,9	99,0 ± 84,1	137,3 ± 112,0	90,4 ± 79,1	36,2 ± 57,6	12,8 ± 19,4	8,8 ± 10,9	3,4 ± 7,3	5,6 ± 15,4	20,3 ± 31,0	38,4 ± 49,5	63,2 ± 57,8	607,2 ± 261,8
19	Parnamirim-PE	87,9 ± 78,7	104,1 ± 69,1	132,5 ± 89,6	78,8 ± 71,1	29,2 ± 33,1	11,7 ± 14,5	9,5 ± 12,8	3,1 ± 5,2	4,7 ± 11,0	13,5 ± 25,3	32,6 ± 44,9	59,3 ± 59,9	566,7 ± 200,6
20	Petrolândia-PE	54,4 ± 55,5	50,4 ± 50,3	82,4 ± 82,8	45,3 ± 51,9	28,9 ± 27,0	25,6 ± 23,2	21,1 ± 21,6	7,7 ± 7,2	8,9 ± 20,9	7,2 ± 11,1	28,6 ± 28,9	39,7 ± 44,2	400,2 ± 178,3
21	Petrolina-PE	71,6 ± 77,1	81,3 ± 81,2	97,4 ± 90,3	53,1 ± 58,6	8,7 ± 16,2	6,0 ± 14,3	3,4 ± 6,1	2,0 ± 4,2	3,8 ± 9,3	11,6 ± 22,3	42,6 ± 45,7	57,4 ± 56,5	438,8 ± 198,2
22	Salgueiro-PE	92,0 ± 71,9	103,3 ± 72,3	147,5 ± 96,7	83,8 ± 65,5	29,2 ± 35,1	10,6 ± 13,9	9,2 ± 12,2	3,6 ± 6,5	6,1 ± 12,0	14,5 ± 22,6	31,8 ± 37,1	56,2 ± 53,1	587,8 ± 191,2
23	Santa Maria da Boa Vista-PE	73,0 ± 86,7	78,8 ± 64,6	110,5 ± 103,1	62,1 ± 66,7	22,6 ± 27,8	8,2 ± 10,2	6,3 ± 11,6	2,0 ± 5,1	2,5 ± 6,3	13,4 ± 24,8	31,3 ± 40,0	52,0 ± 50,6	463,6 ± 231,3
24	São José do Belmonte-PE	95,4 ± 83,3	114,8 ± 82,5	163,3 ± 117,5	105,0 ± 80,7	36,2 ± 36,9	19,8 ± 19,9	12,6 ± 16,1	3,0 ± 5,7	4,4 ± 9,1	10,6 ± 18,1	31,0 ± 41,0	46,5 ± 49,2	642,6 ± 256,6
25	São José do Egito-PE	57,8 ± 62,6	82,1 ± 75,6	119,5 ± 95,3	109,7 ± 87,2	59,6 ± 59,2	33,5 ± 36,4	20,1 ± 24,1	6,6 ± 14,6	3,4 ± 9,1	6,4 ± 16,3	8,1 ± 15,6	24,8 ± 37,6	531,5 ± 287,4
26	Serra Talhada-PE	83,3 ± 82,4	106,1 ± 77,9	146,6 ± 96,5	101,8 ± 68,8	48,9 ± 45,8	27,5 ± 28,9	16,7 ± 18,3	7,4 ± 16,4	5,1 ± 11,3	12,7 ± 22,4	28,0 ± 38,6	50,1 ± 50,7	634,3 ± 240,3
27	Serrita-PE	91,1 ± 72,1	100,4 ± 70,3	141,5 ± 115,3	96,9 ± 78,7	40,4 ± 49,8	12,5 ± 12,7	9,9 ± 13,9	3,0 ± 5,5	3,5 ± 6,6	13,3 ± 18,5	37,9 ± 51,5	65,0 ± 61,0	615,4 ± 240,0
28	Sertânia-PE	53,6 ± 59,1	74,9 ± 59,3	121,1 ± 94,2	97,8 ± 73,7	55,7 ± 49,4	32,2 ± 30,4	22,2 ± 26,3	9,8 ± 13,1	7,4 ± 13,1	16,6 ± 22,7	17,7 ± 26,2	29,3 ± 41,1	538,3 ± 215,1
29	Triunfo-PE	110,7 ± 86,4	153,8 ± 108,9	209,5 ± 124,8	184,8 ± 117,3	146,0 ± 115,4	120,9 ± 82,8	97,0 ± 59,1	46,8 ± 44,3	22,1 ± 24,8	30,4 ± 34,4	37,7 ± 39,9	57,6 ± 51,1	1217,2 ± 377,7
30	Verdejante-PE	84,6 ± 75,0	111,2 ± 114,5	127,3 ± 76,5	98,1 ± 100,9	27,7 ± 34,0	14,3 ± 25,7	8,9 ± 16,0	3,9 ± 11,7	5,2 ± 12,7	8,7 ± 12,4	18,5 ± 24,9	43,0 ± 48,5	551,5 ± 297,3

Table 3: Probability distribution functions that best adjusted the monthly and annual rainfall of time series of the analyzed cities by the Kolmogorov-Smirnov (KS) test with a 5% probability level

	Station	January	February	March	April	May	June	July	August	September	October	November	December	ANNUAL
1	Afogados da Ingazeira-PE	We_3 (0,976)	Fr (0,902)	We_3 (0,993)	We_3 (0,872)	We_3 (0,946)	We_3 (0,941)	Be_4 (0,129)	*	*	*	*	*	Ga_2 (0,996)
2	Afrânio-PE	LN (0,301)	Fr (0,557)	Lo (0,623)	Ga_2 (0,320)	*	*	*	*	*	*	Ga_2 (0,160)	LN (0,290)	Lo (0,954)
3	Araripina-PE	Ga_2 (0,875)	Ga_2 (0,868)	Lo (0,652)	Ga_2 (0,404)	Fr (0,083)	*	*	*	*	*	Lo (0,144)	We_2 (0,576)	LN (0,948)
4	Arcoverde-PE	Ga_2 (0,325)	Ga_2 (0,447)	We_3 (0,303)	Fr (0,465)	Ga_2 (0,576)	Lo (0,571)	Lo (0,366)	Ga_2 (0,686)	*	*	*	*	LN (0,715)
5	Belém de São Francisco-PE	We_3 (0,691)	We_3 (0,996)	We_3 (0,772)	We_3 (0,881)	We_3 (0,205)	We_3 (0,693)	We_3 (0,254)	*	*	*	*	We_3 (0,730)	Lo (0,744)
6	Betânia-PE	We_3 (0,866)	We_3 (0,925)	Ga_2 (0,992)	We_3 (0,688)	Ga_2 (0,433)	We_3 (0,894)	We_3 (0,175)	*	*	*	We_3 (0,096)	Ga_2 (0,207)	Ga_2 (0,964)
7	Bodocó-PE	Lo (0,165)	We_3 (0,978)	GEV (0,980)	We_3 (0,499)	We_3 (0,518)	We_3 (0,155)	We_3 (0,185)	*	*	We_3 (0,063)	We_3 (0,102)	Ga_2 (0,491)	LN (0,565)
8	Cabrobó-PE	We_3 (0,287)	We_3 (0,339)	We_2 (0,493)	We_3 (0,349)	We_3 (0,213)	We_3 (0,138)	We_3 (0,163)	*	*	*	*	Ex (0,282)	Lo (0,974)
9	Custódia -PE	Ga_2(0,331)	We_3 (0,742)	Lo (0,484)	We_2 (0,735)	Ga_2 (0,847)	Lo (0,457)	Ga_2 (0,649)	We_3 (0,556)	*	*	We_3 (0,173)	We_3 (0,285)	Lo (0,833)
10	Exu-PE	Ga_2(0,907)	We_3 (0,780)	Lo (0,982)	We_3 (0,948)	We_3 (0,302)	We_3 (0,486)	Be_4 (0,068)	*	*	*	Be_4 (0,071)	We_3 (0,205)	Lo (0,321)
11	Flores-PE	We_3 (0,953)	Be_4 (0,710)	We_3 (0,943)	GEV (0,990)	We_3 (0,999)	We_3 (0,378)	Be_4 (0,217)	*	*	*	*	Be_4 (0,085)	Ga_2 (0,747)
12	Floresta-PE	Ga_2 (0,680)	We_3 (0,929)	Ga_2 (0,997)	We_3 (0,975)	We_3 (0,823)	We_3 (0,568)	We_3 (0,906)	*	*	*	We_3 (0,038)	We_3 (0,664)	GEV (0,999)
13	Ibimirim-PE	We_3 (0,571)	We_3 (0,820)	We_3 (0,515)	We_3 (0,868)	We_3 (0,277)	We_3 (0,796)	We_3 (0,192)	*	*	*	Be_4 (0,051)	We_3 (0,386)	Fr (0,922)
14	Iguaraci-PE	Er (0,964)	Fr (0,800)	We_2 (0,953)	Ga_2(0,855)	We_3 (0,622)	No (0,844)	We_3 (0,605)	*	*	*	Be_4 (0,147)	Ex (0,306)	We_3 (0,894)
15	Inajá-PE	We_3 (0,294)	We_3 (0,984)	Ex (0,859)	Be_4 (0,596)	Ga_2 (0,857)	We_3 (0,965)	Lo (0,699)	We_3 (0,947)	*	*	We_3 (0,252)	We_3 (0,714)	GEV (0,850)
16	Ipubi-PE	We_2 (0,995)	We_3 (0,991)	Lo (0,500)	We_3 (0,966)	We_3 (0,835)	We_3 (0,613)	We_3 (0,221)	*	*	We_3 (0,074)	We_3 (0,373)	We_3 (0,792)	LN (0,944)
17	Itapetim-PE	Lo (0,504)	We_3 (0,631)	Fr (0,980)	We_3 (0,332)	Er (0,793)	Ex (0,447)	Ga_2 (0,303)	*	*	*	*	Be_4 (0,133)	Lo (0,639)
18	Ouricuri-PE	We_3 (0,988)	Ga_2 (0,748)	We_3 (0,986)	We_3 (0,561)	We_3 (0,071)	*	*	*	*	*	We_3 (0,062)	We_3 (0,629)	Fr (0,883)
19	Parnamirim-PE	We_3 (0,918)	We_3 (0,999)	We_3 (0,981)	We_3 (0,828)	Be_4 (0,169)	Be_4 (0,076)	*	*	*	*	We_3 (0,277)	Ex (0,867)	GEV (0,907)
20	Petrolândia-PE	Be_4 (0,303)	We_3 (0,880)	We_3 (0,633)	We_3 (0,591)	We_3 (0,434)	We_3 (0,635)	We_3 (0,423)	We_3 (0,675)	We_3 (0,122)	*	We_3 (0,243)	Ex (0,429)	GEV (0,882)
21	Petrolina-PE	We_3 (0,739)	We_3 (0,550)	We_3 (0,815)	We_3 (0,591)	*	*	*	*	*	*	Be_4 (0,188)	We_3 (0,857)	Ga_2 (0,941)
22	Salgueiro-PE	Ga_2 (0,953)	Ga_2 (0,984)	Be_4 (0,699)	We_3 (0,895)	We_3 (0,210)	We_3 (0,414)	*	*	*	*	We_3 (0,825)	Ga_2 (0,974)	GEV (0,993)
23	Santa Maria da Boa Vista-PE	We_3 (0,995)	Be_4 (0,744)	We_3 (0,756)	We_3 (0,656)	We_3 (0,111)	*	*	*	*	*	*	Ga_2 (0,446)	Fr (0,984)
24	São José do Belmonte-PE	We_3 (0,506)	Fr (0,710)	Lo (0,272)	We_3 (0,743)	We_3 (0,483)	We_3 (0,135)	*	*	*	*	Be_4 (0,051)	Ga_2 (0,189)	Lo (0,448)
25	São José do Egito-PE	We_3 (0,349)	We_3 (0,484)	We_3 (0,858)	Fr (0,655)	We_3 (0,607)	We_3 (0,454)	Be_4 (0,059)	*	*	*	*	*	No (0,964)
26	Serra Talhada-PE	Ga_2 (0,661)	We_3 (0,792)	We_3 (0,827)	Ga_2 (0,843)	We_3 (0,921)	We_3 (0,935)	Be_4 (0,235)	*	*	*	We_3 (0,089)	We_3 (0,823)	Lo (0,998)
27	Serrita-PE	We_3 (0,901)	We_3 (0,995)	We_3 (0,970)	We_3 (0,825)	We_3 (0,429)	We_3 (0,278)	*	*	*	*	We_3 (0,460)	We_3 (0,880)	Ga_2 (0,708)
28	Sertânia-PE	We_3 (0,667)	GEV (0,679)	Ga_2 (0,919)	We_3 (0,881)	We_3 (0,896)	We_3 (0,894)	We_3 (0,734)	*	*	*	*	*	Ga_2 (0,994)
29	Triunfo-PE	Ga_2 (0,281)	Ga_2 (0,190)	Fr (0,273)	GEV (0,683)	Ga_2 (0,078)	We_3 (0,275)	Lo (0,578)	We_3 (0,158)	Ex (0,150)	We_3 (0,063)	Ga_2 (0,134)	We_3 (0,214)	Lo (0,849)
30	Verdejante-PE	We_3 (0,681)	Ex (0,364)	GEV (0,808)	Ga_2 (0,775)	We_3 (0,171)	We_3 (0,074)	*	*	*	*	*	We_3 (0,129)	Lo (0,616)

Probability Distribution Functions - Be_4: Beta (type 4); Er: Erlang; Ex: Exponential; Fr: Fréchet (Fisher-Tippett type 2); Ga_2: Gamma (type 2); GEV: Generalizada de ValoresExtremos; LN: Log-Normal; Lo: Logistic; No: Normal; Wr_2: Weibull (type 2); Wr_3: Weibull (type 3); (*) The sample data didn't adjusted for any distributions evaluated; (p-value).

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Geochemical Investigation of Groundwater in Some Parts of Birnin Kebbi, Northwestern Nigeria

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Abstract- Geochemical study on groundwater quality was undertaken from Bayankara, Badariya and Old Town areas in Birnin Kebbi, situated in sedimentary basin, northwestern Nigeria. The hydrogeochemical study was carried out on 30 water samples, 10 from each of the 3 locations with the intent to determining the quality of the water sources such as tap water, borehole, and hand-dug well used for drinking and domestic purposes; to determine the causes, sources of the pollutants and suggest solutions towards solving the problem. The 30 water samples were analyzed for major elements and important anions. Atomic Absorption Spectrometer (AAS) was used to analyze the cations while NO_3^-, PO_4^{3-} and SO_4^{2-} were determined using Spectrophotometer. Both F^- and Cl^- were determined by titration method.

Keywords: *geochemical, groundwater, anthropogenic, leaching, contaminant.*

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Ola-Buraimo A. O. [α] & Ologe O. [σ]

Abstract- Geochemical study on groundwater quality was undertaken from Bayankara, Badariya and Old Town areas in Birnin Kebbi, situated in sedimentary basin, northwestern Nigeria. The hydrogeochemical study was carried out on 30 water samples, 10 from each of the 3 locations with the intent to determining the quality of the water sources such as tap water, borehole, and hand-dug well used for drinking and domestic purposes; to determine the causes, sources of the pollutants and suggest solutions towards solving the problem. The 30 water samples were analyzed for major elements and important anions. Atomic Absorption Spectrometer (AAS) was used to analyze the cations while NO_3^-, PO_4^{3-} and SO_4^{2-} were determined using Spectrophotometer. Both F^- and Cl^- were determined by titration method.

The results show that all the cations Na, K, Ca, Mg, Fe, Cu, and Zn ions have values far less than maximum limit recommended by WHO except Mn ion that exhibits average concentration values in Bayankara 0.39mg/l, Badariya 0.16mg/l greater than 0.05mg/l tolerable limit by WHO standard. However, Old Town area has Mn ion values within the recommended limit. PI index on manganese ion further show that Bayankara is more polluted than Badariya having PI index > 1 probably due to unhygienic conditions of the areas and possibly due to dissolution of manganese mineral present in the sandstone aquifer.

The anions analyzed Cl, F, NO_3 and SO_4 have ion concentrations within the limits of WHO recommended for drinking water with the exception of NH_4 and PO_4 ion concentration values that are anomalously high in the 3 locations; showing values greater than 0.5mg/l for NH_4 and 0.3mg/l for PO_4. In Bayankara, average NH_4 and PO_4 ion concentration values are 3.7mg/l and 0.81mg/l respectively; Badariya, 4.0mg/l and 0.75mg/l respectively, while Old Town is 3.8mg/l and 0.87mg/l respectively. The contaminants resulted from anthropogenic means such as poor hygienic condition from sewage leaching and excessive application of leached fertilizer and manure rich in PO_4 and NH_4 in farming, aided by tectonic and sedimentary structures that characterize the study areas.

Keywords: geochemical, groundwater, anthropogenic, leaching, contaminant.

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I. Introduction

Geochemical study of water quality in Birnin kebbi, kebbi State, Nigeria became very important considering the geometric rise in population due to urbanization, citing of Federal University and relatively peaceful security atmosphere in the state capital. The study area is geologically mainly sedimentary terrain consisting exclusively of Gwandu Formation. Geologically, the study area is characterized by two types of structures, categorized into sedimentary and tectonic structures (Ola-Buraimo *et al*., 2019). The study area consists of 3 different parts of Birnin Kebbi, covering Bayankara, Badariya and Old Town; situated in the southwestern and southeastern part of Birnin Kebbi (Fig. 1).

The structural pattern from field investigation shows that the structural intensity vary from place to place but intensively reported in Badariya, Bayankara and comparatively low in Old Town (Ola-Buraimo *et al*., 2019). Study on the geochemistry of water supply in Birnin Kebbi is not well documented except the recent one on the geology and microbiological investigation of different sources of water supply in Birnin Kebbi area (Ola-Buraimo *et al*., 2019). However, other recently investigated works on the geochemistry of water in the Cretaceous basement complex of Kebbi State was reported in the works of Wali *et al*. (2018a, b and 2019). On a wider scale quite a number of documented groundwater researches were carried out on Sokoto Basin, these include the works of Anderson and Ogilbee (1973), Adelana *et al*. (2003), Ekpoh and Ekpeyong (2011), Amadi *et al*. (2015), and Ette *et al*. (2016). Other notable researchers are Toyin *et al*. (2016), Wali *et al*. (2016), Wali *et al*. (2018a, 2018b and 2019). Importantly the works of Wali *et al*. (2018a, 2018b and 2019) were hydrochemical studies on basement complex area of Kebbi State unlike the sedimentary basin aspect of Kebbi State (Birnin Kebbi) that this study focused on. The hydrogeochemical study of different sources of water such as borehole, public tap water and hand-dug wells and there suitability for consumption is imperative considering the consequence of unsafe water supply to the inhabitants.

This study is principally investigated to determine the groundwater quality of the populated

parts of Birnin Kebbi viz-a-viz the impact of the poor sanitary condition and the effect of the geologic facies (aquifer) interaction with the groundwater system in the area and to compare the presence of chemical elements and compounds present with the World Health Organization Standard in order to know if the groundwater consumed through different sources by the populace is of good quality and safe for drinking and possibly there would be need for remediation of the water system before consumption.

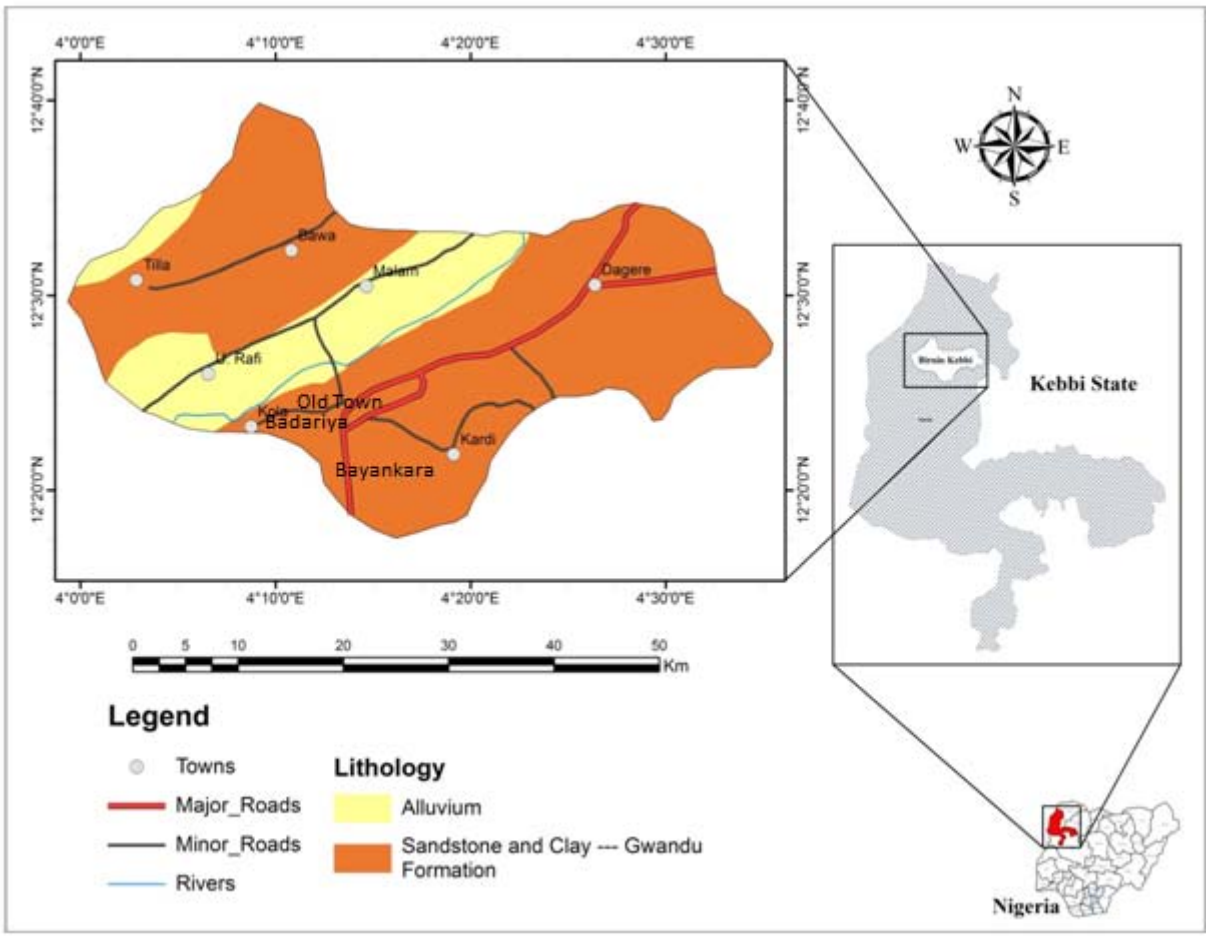

Figure 1: Location map of the study area, Birnin Kebbi, Nigeria (After Ola-Buraimo *et al*., 2019)

II. Geology of the Area

a) The Gwandu Formation

The sedimentary deposit of the study area belongs to Gwandu Formation, with type section and type area in the Gwandu Emirate of northwestern Nigeria (Kogbe, 1972). Outcrops of the formation cover a vast area dotted with a number of prominent ridges and groups of flat-topped, steep-sided hills capped by ironstone. Some of the isolated hills covered with ironstone debris occur in all stages of disintegration due to varying degree of weathering, rising out of the sandy plain over which the products of erosion have been distributed. The hills are flat at the top but steep sided with falloff of ironstone boulders on it and screes at the foot of the hills.

The best outcrops of the Gwandu Formation occur around Birnin-Kebbi and Argungu. The sediments consist of massive white clays interbedded with coarse and medium-grained red sandstones and mudstones with occasional peat bands. The type section proposed for the formation by Kogbe (1976d) shows the typical lithologic characteristic of the formation. By correlation with palynomorphs from tropical Tertiary deposits earlier mentioned, the age of the Gwandu Formation was tentatively put as Eocene- Miocene (Kogbe, 1976d); but this is yet to be corroborated by recent studies.

The geology of the study area is not well documented; the few field work on the geology of the area located within the Birnin Kebbi has been a private property of Department of Geology, Federal University Birnin Kebbi, Nigeria. The only recent and documented field geology of the study area is contained in the work of Ola-Buraimo *et al*. (2019). The geology of the area was described to contain different lithofacies varying from one location to another. Generally, the litho-sequence was described to vary from high energy fluviatile deposits of poorly sorted sandstone sitting unconformably on conglomeratic bed.

The conglomerate is underlain by sandstone, siltstone and carbonaceous shale at the bottom; suggesting downward decrease in grain size and energy of transportation and deposition of the sediments (Ola-Buraimo *et al*., 2019). The downward sequence was described to indicate varying paleo environment of deposition, suggested to vary from fluviatile environment at the top, but prograded into deltaic setting at the bottom (Ola-Buraimo *et al*., 2019).
In other parts of the study area especially at Dukku River, close to Kebbi State Water cooperation, the facies vary considerably displaying cyclic deposit of claystone and sandstone. A part of the sequence shows evidence of macrofossils suggesting deposition of the facies in a marine setting. However, not too far from the conspicuous outcrop is a great vast exposure of fine grain, well sorted sandstone characterized by cross lamination, well rounded grains suggesting recycled sediment of fluviatile deposit.

Therefore, field evidence from field work conducted in this research suggests that most of the aquifers within the Birnin kebbi are located in the well sorted fine sandstone; this may be responsible for high yield of groundwater in the study area.

Structural features of the study area are well documented in the work of Ola-Buraimo *et al*. (2019). The structures are described to be of two types; sedimentation and tectonic structures. The tectonic structures are mainly faults, joints and fractures which characterize the sediment deposits in Birnin Kebbi, resulting to gullies and poor road networks in the interiors and house failures. However, the sedimentary structures are bedding, cross lamination, channel fills, clinoform, load cast, bioturbation and ichnofossils (Ola-Buraimo *et al*., 2019). Ola-Buraimo *et al*. (2019) posited that the geologic structures are one of the contributory factors serving as conduit and responsible for rapid drive of pathogens, contaminating the groundwater system; thereby make the water unclean and unsafe for human consumption.

III. Materials and Methods

Three locations- Bayankara, Badariya and Old Town are parts of Birnin Kebbi selected for hydrogeochemical study based on population, social economic activities and environmental sanitation standard of the residents. There are different sources of water supply in the areas such as borehole, public tap water and hand-dug wells. They serve as sources of collecting water samples for geochemical analysis. The water samples collected from the borehole were represented by “bg”, public tap water represented by “tg” and hand-dug well represented by “wg”. The collection of water samples from the 3 locations was randomly carried out, spread across the investigated areas.

At the visited locations, the borehole waters were stored in overhead tanks mostly privately owned but made accessible for public use outside the compounds. The public taps water are sparsely located and in all cases were erected in public places for use, while the hand-dug wells were only encountered at Bayankara area, mostly characterized by unhygienic conditions where the wells were left uncovered, waterlogged surroundings and un-kept fetchers dropped in the dirty waterlogged surrounding of the wells.

IV. Water Sampling

Thirty water samples, ten each from the locations were collected into 75cl sterile plastic bottles from borehole, public tap water and hand-dug wells. The collected water samples were chlorinated with drops of concentrated hydrochloric acid (HCl) for preservation in the field. The collected samples were later preserved in refrigerator for about a week to complete the sample collection exercise before transportation to the laboratory. Field observations were noted in the field note book by considering sampling points and location names; bottles were well labeled and coded to reflect the location name, type of source water collected– borehole (bh), public tap water (pt), hand dug well (hd) and location number.

Water samples collected undergo laboratory tests to determine the concentration of major cations such as Mg^{2+}, Ca^{2+}, Na^{+}, K^{+}, Fe^{2+}, Cu^{2+}, Zn^{2+} and Mn^{+}, while major anions considered are F^{-}, Cl^{-}, SO_4^{2-}, NO_3^{-} and PO_4^{3-}. The major elements were analyzed using Atomic Absorbtion Spectrometer (AAS) Perkin Elmer, while for the anions, the NO_3^{-}, PO_4^{3-}, NH_3^{2-} and SO_4^{2-} were determined using Spectrophotometer (Model Genesys 20); F^{-} and Cl^{-} were determined by titration in chemical units. The results obtained were compared with recommended standards to determine the water geochemistry and its quality for drinking and domestic purposes.

V. Results and Interpretation

The summary of the concentrations of dissolved elements in the groundwater collected from Bayankara, Badariya and Old Town in Birnin Kebbi, Kebbi State, northwestern Nigeria is presented in Tables 1-3. Analytical results of investigated cations and anions were compared with United State Environmental Protection Standards and World Health Organisation standards. The initial standards considered include maximum contaminant levels (MCLs), secondary maximum contaminant levels (SMCLs) erected by USEPA (2012) and WHO (2012). The implications of the MCLs are the enforceable standards which specify allowable level of a contaminant in public water.

VI. Bayankara

The geochemical analysis of water samples from Bayankara show that Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Cu^{2+} and Zn^{2+} contain contamination values that are within standard limits of WHO (2012) standards (Fig. 2). The Na^+ concentration shows a minimum value of 4.1mg/l, highest value of 7.24mg/l and an average value of 7.51mg/l (Fig. 3). These values are far less than the maximum concentration limit specified by WHO put at 200mg/l. Potassium ion (K^+) concentration vary between 3.95-9.11mg/l and an average of 5.92mg/l compared to 200mg/l of WHO standard. Thus, K+ concentration is safe and fall less than the maximum limit of 200mg/l specified by WHO (2012). Ca+ varies from 9.6 to 31.6mg/l; average value of 14.05mg/l, less than the 75mg/l specified limit by WHO. Magnesium ion (Mg^+) concentration varies between 2.14-4.65mg/l, average value of 3.65mg/l compared to 50mg/l standard limit (Fig. 4). Fe^{2+} concentration varies from 0.20-0.77mg/l with average value of 0.41mg/l compared with 1.0mg/l standard limit. Zinc ion (Zn^{2+}) concentration follows same trend with others varying in concentration from 0.00-0.07mg/l, average value of 0.04mg/l compared with 5.0mg/l as standard limit.

However, Manganese ion (Mn^+) concentration value in the water samples ranges from 0.04-0.82mg/l, average value is 0.39mg/l compared to 0.05mg/l recommended limit value. The recorded Mn^+ values from the 10 samples are greater than the recommended value. Therefore, the Mn ion is the only cation found having more concentration values greater than the recommended value for drinking water. This concentration anomaly may be as a result of reactions between the groundwater and the aquifer minerals. However, since most of the stratigraphy sequences are mostly clastic and siliciclastic facies, then some of the Mn ion could be antropogenic in nature. However, the low values of other cations in the analyzed water samples from Bayankara suggest that the aquifer is mainly sandstone and not readily weathered into solution. The overlying claystones and sandstones did not weather by dissolution method. The effect of weathering and mineral dissolution in sedimentary basins cannot be compared with basement complex which contains minerals such olivine, pyroxene, amphibolites, feldspar, mica and quartz in varying composition depending on the rock type in higher concentration than sedimentary rocks.

The anions which include Cl, F, NO_3 and SO_4 ions have their concentration values lower than the WHO maximum limits while NH_4^+ and PO_4^{2+} recorded concentration values greater than the recommended limits (Fig. 5). The NH_4 ion concentration varies between 2.0-5.0mg/l with an average value of 3.7mg/l compared to maximum recommended limit of 0.5mg/l. In the case of PO_4 ion, the concentration value recorded in the 10 sample show a range of 0.6-1.2mg/l with an average value of 0.81mg/l compared to WHO standard limit of 0.3mg/l.

The manganese, though it is an essential element needed by man but its excess concentration intake from water could lead to neurological effects (Canavanet *et al*., 1934; Cook *et al*., 1974; Roels *et al*., 1999; ATSDR, 2000). High manganese intake can as well lead to diseases-like syndrome such as weakness, anorexin, muscle pain, apathy, slow speech, monotonous tone of voice, emotionless facial expression and slow clumsy movements of limbs.

Table 1: Summary of geochemical analysis of water samples from Bayankara area

Loc.	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	Fe mg/l	Cu mg/l	Zn mg/l	Mn mg/l	Cl mg/l	F mg/l	NO^-_3 mg/l	NH_4 mg/l	PO_4 mg/l	SO^{2-}_4 mg/l
K1bg	5.25	6.35	14.80	3.64	0.05	0.28	0.05	0.14	4.22	0	0.047	3	0.8	0.034
K2bg	4.1	8.99	13.60	4.65	0.05	0.20	0.03	0.22	2.13	0	0.027	3	0.6	0.123
K3bg	5.15	5.49	12.20	3.40	0.05	0.79	0.07	0.40	8.24	0	0.019	5	0.6	0.135
K4bg	4.2	6.35	9.60	4.50	0.03	0.18	0.02	0.54	5.83	0	0.027	4	1.2	0.012
K5bg	7.24	5.51	12.90	2.44	0.01	0.40	0.04	0.14	5.53	0	0.009	2	0.8	0.016
K6bg	5.65	9.11	10.20	3.30	0.06	0.22	0.03	0.82	7.75	0	0.030	4	0.8	0.208
K7wg	4.25	5.44	13.80	4.40	0.04	0.40	0.00	0.64	4.36	0	0.056	4	1.0	0.205
K8bg	5.20	3.95	31.60	4.20	0.04	0.38	0.05	0.74	3.16	0	0.043	4	0.8	0.018
K9wg	4.25	3.99	11.40	2.50	0.06	0.60	0.05	0.22	3.36	0	0.042	5	0.7	0.114
K10bg	5.7	3.99	10.40	3.55	0.08	0.65	0.04	0.04	5.12	0	0.034	3	0.8	0.123
High-Est	7.24	9.11	31.6	4.65	0.08	0.79	0.07	0.82	8.24	0	0.056	5	1.2	0.208
Low-Est	4.1	3.95	9.6	2.44	0.01	0.20	0.00	0.04	2.13	0	0.009	2	0.6	0.012
Ave-rage	5.10	5.92	14.05	3.65	0.05	0.41	0.04	0.39	4.97	0	0.033	3.7	0.81	0.098
WHO mg/l	200	200	75	50	0.3	1.0	5.0	0.05	250	1.4	45	0.5	0.3	250

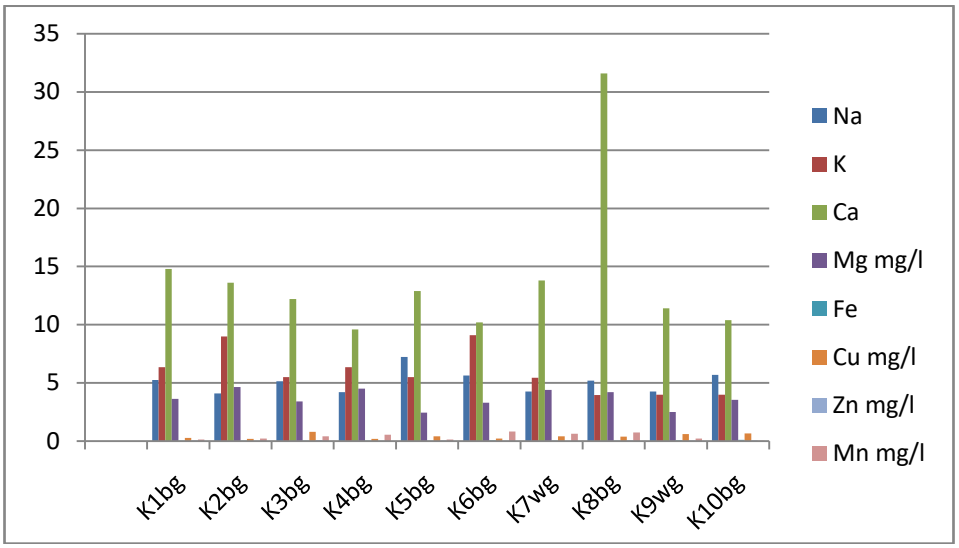

Figure 2: Summary of geochemical analysis of major elements in Bayankara area

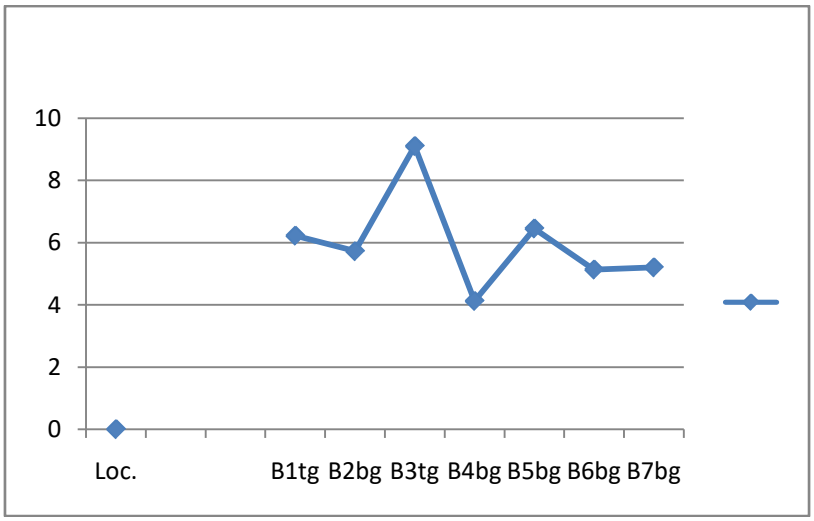

Figure 3: Variation plot of Na ion concentration in Bayankara area

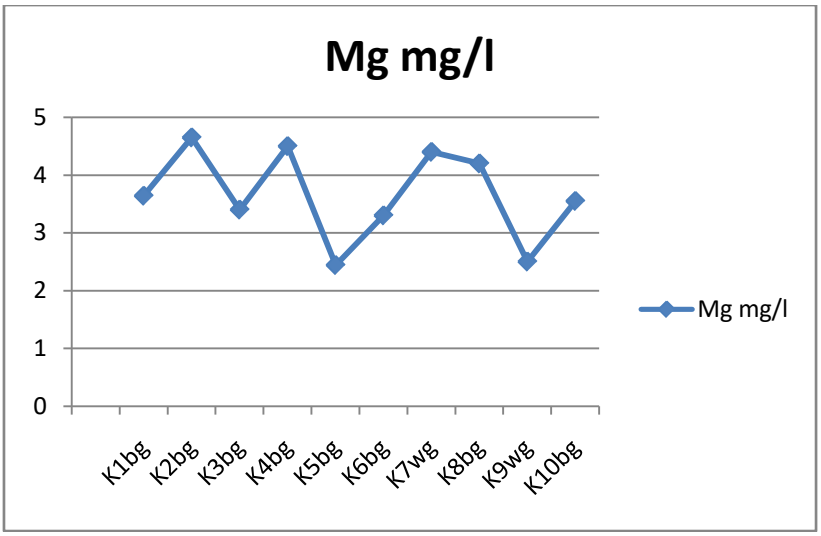

Figure 4: Variation plot of Mg ion concentration in Bayankara area

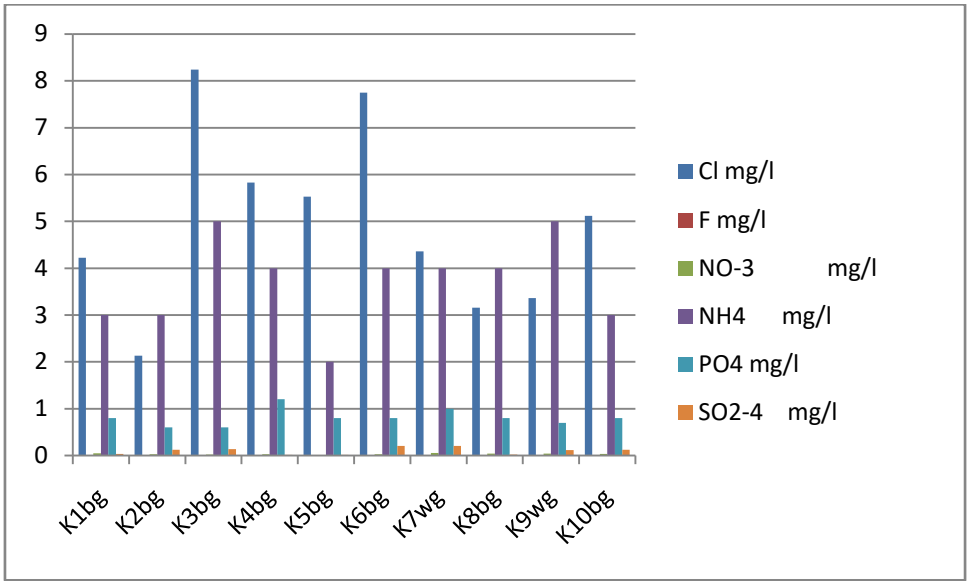

Figure 5: Summary of geochemical analysis of Anion elements in Bayankara area

VII. Badariya

The Badariya area with locations B1-B10 show the same trend of cations concentration with values very low compared to WHO standard limits, thus, meeting the required limits for good water quality (Figs. 6, 7). However, the manganese ion concentration of higher value was noticed at locations B1tg, B2bg, B3tg and B4bg only out of 10 locations (Table2). The Mn ion values vary between 0.14-0.54mg/l compared to 0.05mg/l standard maximum limit recommended by WHO (2012). The anions concentration values in Badariya also follow the same trend with that of Bayankara area where Cl, F, NO_3 and SO_4 have concentration levels within the standard limits of WHO (2012) with the exception of NH_4 and PO_4 (Table 2, Fig. 8). The phosphorous ion concentration values vary from 0.6-1.2mg/l, exceeding the standard concentration limit of 0.3mg/l. The NH4 ion concentration value at Badariya varies from 2.0-5.0mg/l with an average value of 4.0mg/l; exhibiting values greater than standard WHO limit of 0.5mg/l (Table 2).

Table 2: Summary of geochemical analysis of water samples from Badariya area

Loc.	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	Fe mg/l	Cu mg/l	Zn mg/l	Mn mg/l	Cl mg/l	F mg/l	NO^-_3 mg/l	NH_4 mg/l	PO_4 mg/l	SO^{2-}_4 mg/l
B1tg	6.22	9.01	33.60	4.55	0.06	0.47	0.02	0.54	4.15	0	0.074	5	0.6	0.014
B2bg	5.72	5.44	12.80	4.74	0.06	0.60	0.02	0.54	5.20	0	0.049	2	1.0	0.013
B3tg	9.10	4.36	11.20	5.53	0.03	-0.50	0.06	0.14	2.55	0	0.044	4	0.6	0.205
B4bg	4.12	4.98	12.10	3.40	0.09	0.25	0.04	0.22	7.65	0	0.028	5	0.6	0.017
B5bg	6.45	4.04	14.30	3.20	0.06	0.30	0.05	0.04	4.37	0.1	0.016	3	0.8	0.055
B6bg	5.13	5.49	17.90	4.50	0.06	0.25	0.08	0.04	3.12	0	0.038	5	0.7	0.074
B7bg	5.2	6.49	19.60	4.80	0.06	-0.20	0.05	0.04	3.38	0	0.057	2	1.2	0.148
B8bg	4.10	5.51	29.80	3.60	0.09	0.53	0.05	0.02	5.27	0	0.066	4	0.6	0.135
B9bg	5.2	8.84	7.60	4.51	0.08	0.25	0.04	0.02	3.12	0	0.038	5	0.6	0.089
B10bg	5.7	5.39	12.30	3.64	0.01	0.01	0.02	0.04	3.33	0	0.007	4	0.8	0.015
High-Est	9.1	9.01	33.6	4.80	0.09	0.60	0.08	0.54	7.65	0.1	0.074	5	1.2	0.205
Low-Est	4.10	4.04	7.60	3.20	0.03	-0.20	0.02	0.02	2.55	0	0.007	2	0.6	0.013
Ave-rage m/l	5.69	5.96	17.12	4.23	0.06	0.20	0.04	0.16	4.21	0.02	0.042	4.0	0.75	0.077
WHO STD	200	200	75	50	0.3	1.0	5.0	0.05	250	1.4	45	0.5	0.3	250

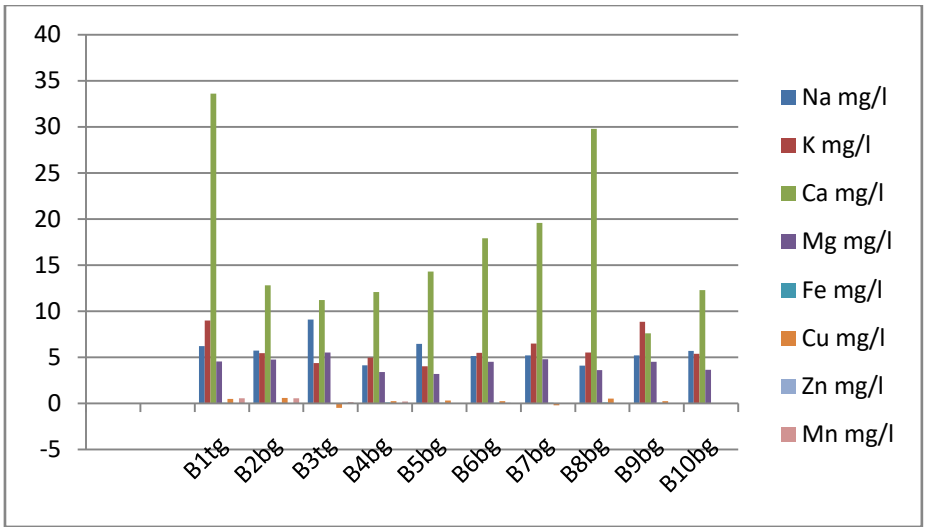

Figure 6: Summary of geochemical analysis of major elements in Badariya area

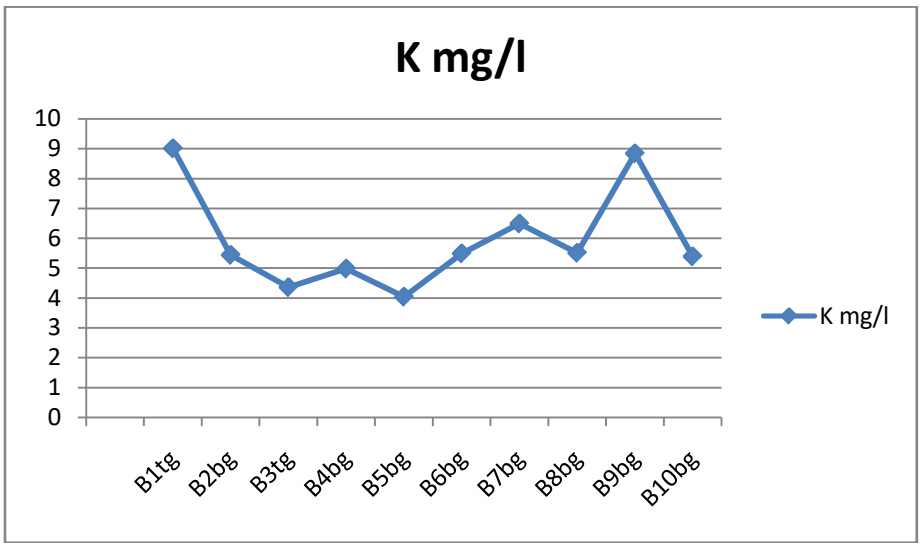

Figure 7: Variation plot of K ion concentration in Badariya area

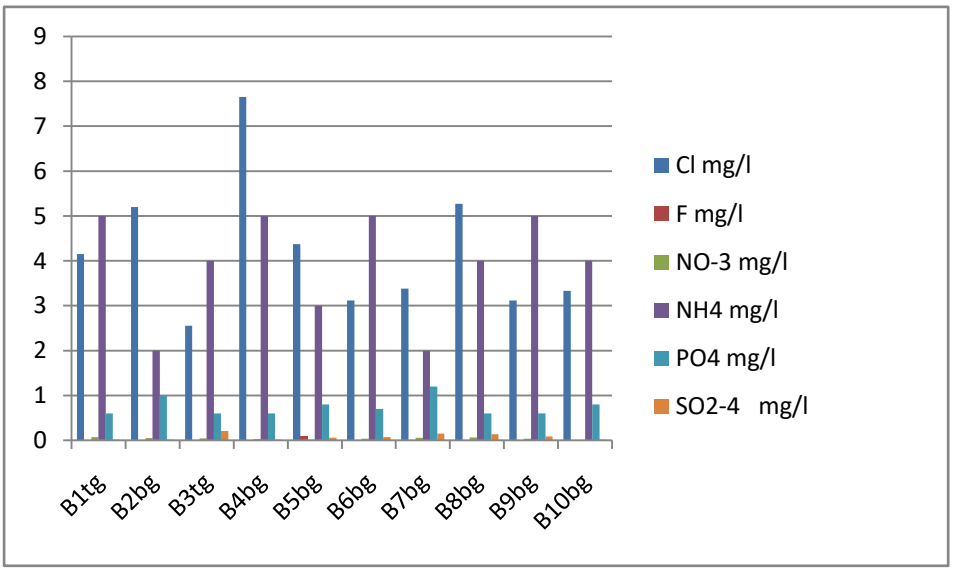

Figure 8: Summary of geochemical analysis of anion elements in Badariya area

VIII. Old Town

Old Town water sample analysis for both cations and anions concentration values are presented in Table 3. The Na, K, Ca, Mg, Fe, Cu and Zn concentration values are within the prescribed limits by WHO (2012), thereby, tentatively classifying the water to be good and healthy for consumption (Fig. 9, 10). However, the other two location involving Bayankara and Badariya have all their samples tested for high Mn ion concentration, no sample location out of 10 locations in Old Town had Mn concentration values greater than WHO standard limit. The Mn ion concentration values range from 0.02-0.04mg/l with an average value of 0.03mg/l. The trend deviates from those values obtained from Bayankara and Badaraya areas. It is opined that this could be as a result of better hygienic condition of Old Town than Bayankara and Badariya areas in terms of sanitation and protection and preservation of contamination of their groundwater from anthropogenic sources.

Anions such as Cl^-, F^-, NO_3^{3-} and SO_4^{2-} have concentration values lower than their recommended standards by WHO (2012). The other two anions NH_4 and PO_4 ions have concentration values greater than required limits (Fig. 11). The NH_4 concentration values range from 2.0-6.0mg/l with an average of 3.8mg/l compared to 0.5mg/l standard limit by WHO (2012). The phosphorous (PO_4^{3-}) ion concentration value ranges between 0.7-1.2mg/l with an average of 0.87mg/l compared with 0.3mg/l recommended allowable maximum concentration limit for portable water (Table 3).

Table 3: Summary of geochemical analysis of water samples from Old Town area

Loc.	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	Fe mg/l	Cu mg/l	Zn mg/l	Mn mg/l	Cl mg/l	F mg/l	NO_3^- mg/l	NH_4 mg/l	PO_4 mg/l	SO_4^{2-} mg/l
O1bg	4.4	3.89	16.20	4.60	0.09	0.02	0.02	0.04	5.14	0.2	0.08	3.0	0.8	0.20
O2bg	4.8	3.99	18.80	3.70	0.09	0.07	0.06	0.04	5.20	0.0	0.06	4.0	0.8	0.14
O3bg	6.1	4.09	11.90	4.61	0.07	0.02	0.04	0.04	3.12	0.0	0.03	4.0	1.2	0.09
O4bg	4.6	6.59	12.60	5.44	0.08	0.20	0.05	0.02	3.33	0.0	0.04	2.0	1.0	0.02
O5bg	5.0	5.49	16.20	4.20	0.09	0.43	0.02	0.04	5.14	0.0	0.01	4.0	0.7	0.20
O6bg	9.1	4.36	18.80	4.40	0.09	0.02	0.06	0.04	4.15	0.1	0.08	6.0	0.8	0.23
O7bg	4.1	4.98	11.90	3.30	0.08	0.07	0.40	0.04	5.66	0.0	0.06	4.0	0.8	0.02
O8bg	6.5	4.04	12.60	4.51	0.08	0.04	0.05	0.04	2.57	0.0	0.03	4.0	0.8	0.11
O9tg	5.4	5.49	14.30	5.14	0.07	0.22	0.05	0.02	5.69	0.0	0.06	3.0	1.0	0.13
O10tg	5.2	6.49	17.90	4.20	0.08	0.44	0.02	0.04	3.12	0.0	0.05	4.0	0.8	0.08
High-Est	9.1	6.59	18.80	5.44	0.09	0.44	0.40	0.04	5.69	0.2	0.08	6.0	1.2	0.23
Low-Est	4.1	3.89	11.90	3.30	0.07	0.22	0.02	0.02	2.57	0.0	0.01	2.0	0.7	0.02
Ave-rage	5.52	4.94	15.12	4.41	0.08	0.09	0.08	0.03	4.31	0.05	0.05	3.8	0.87	0.12
WHO STD	200	200	75	50	0.3	1.0	5.0	0.05	250	1.4	45	0.5	0.3	250

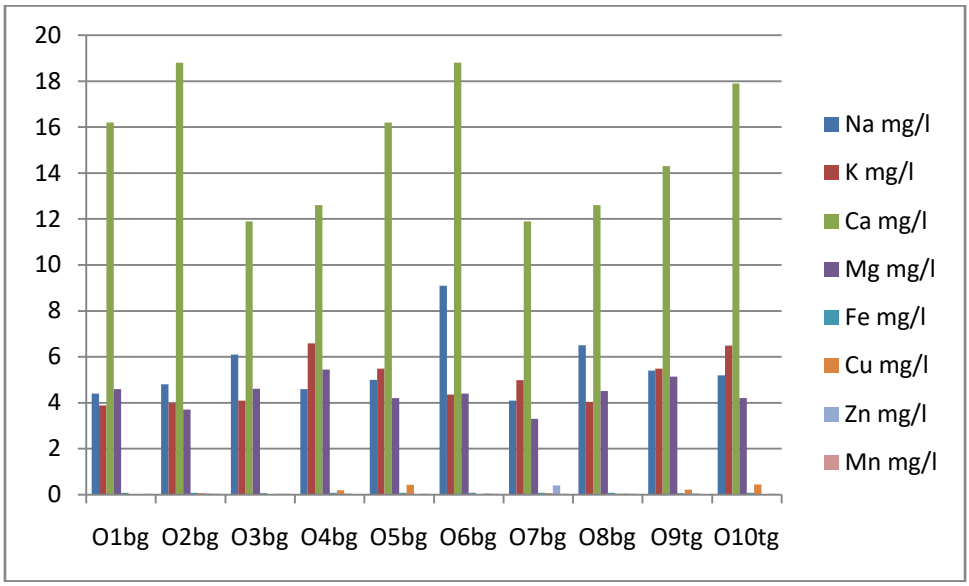

Figure 9: Summary of geochemical analysis of major elements in Old Town

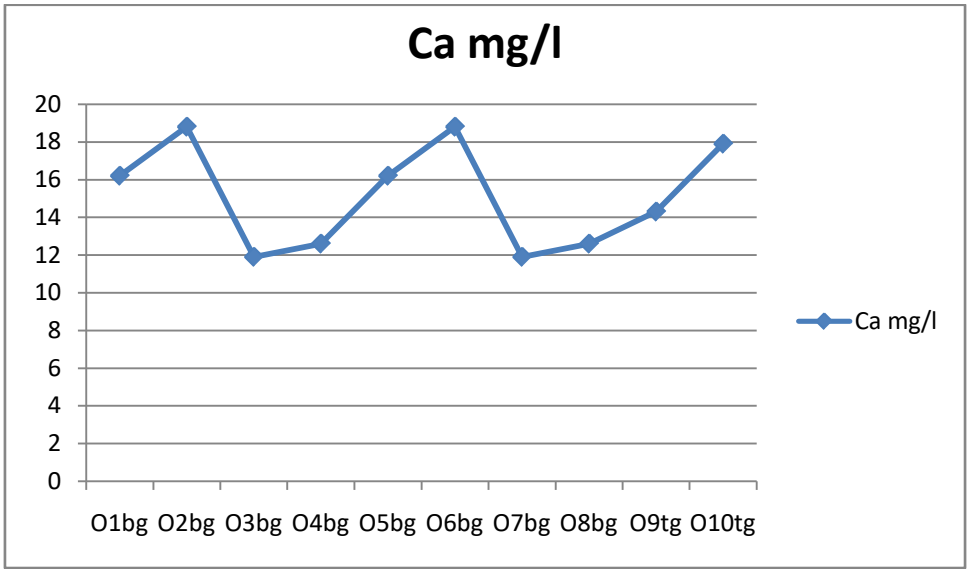

Figure 10: Variation plot of Ca ion concentration in Old Town area

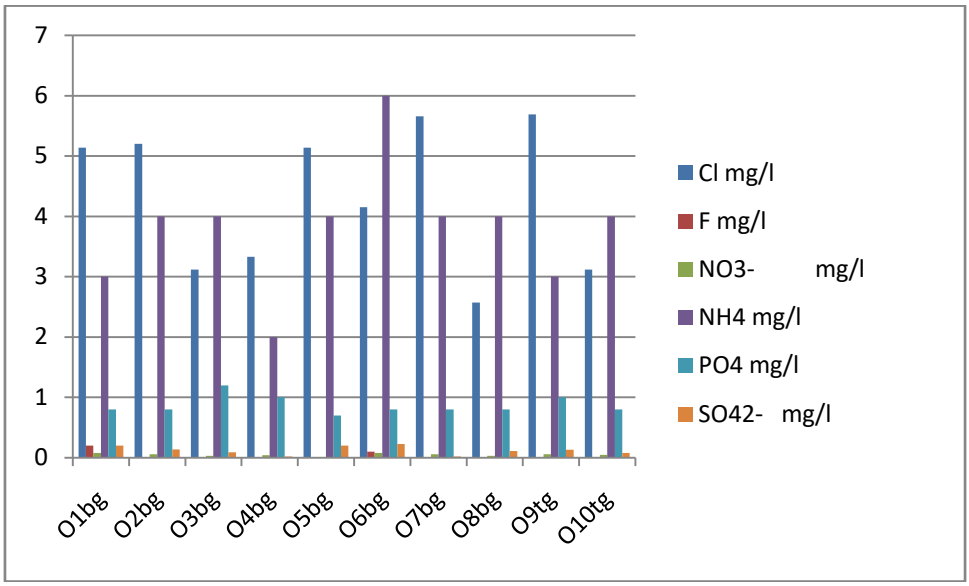

Figure 11: Summary of geochemical analysis of anion elements in Old Town

In this study pollution index was used to further evaluate the degree of major metal contamination in the water samples. Adopted is US Environmental Protection Agency (2002, 2008 and 2009). The pollution index (PI index) depicts the allowable levels of elemental concentration limits safe for human consumption. Therefore, United State Environmental Protection Agency (2012) tolerable level was used for water and the pollution index was calculated using the formula:

PI = (Heavy metal concentration in water/Tolerable level / Number of heavy metals

Among the major elements analyzed for the water samples in the 3 areas of study only Mn ion show evidence of ion concentration higher than the recommended WHO limit while all other heavy metals such as Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Fe^{2+} CU^{2+} and Zn^{2+} have ion concentration lower than the WHO standard tolerable limit. Therefore, PI index was calculated only for Mn ion for the Bayankara and Badariya areas that are characterized with higher Mn level greater than WHO (2012) standard limit. Water samples with pollution index > 1 is regarded as being contaminated but the values obtained for Bayankara water samples suggests that five locations K3bg, K4bg, K6bg, K7wg and K8bg have PI index > 1 (Fig. 12). Therefore, those locations are classified to have polluted water unfit for drinking based on manganese level above recommended.

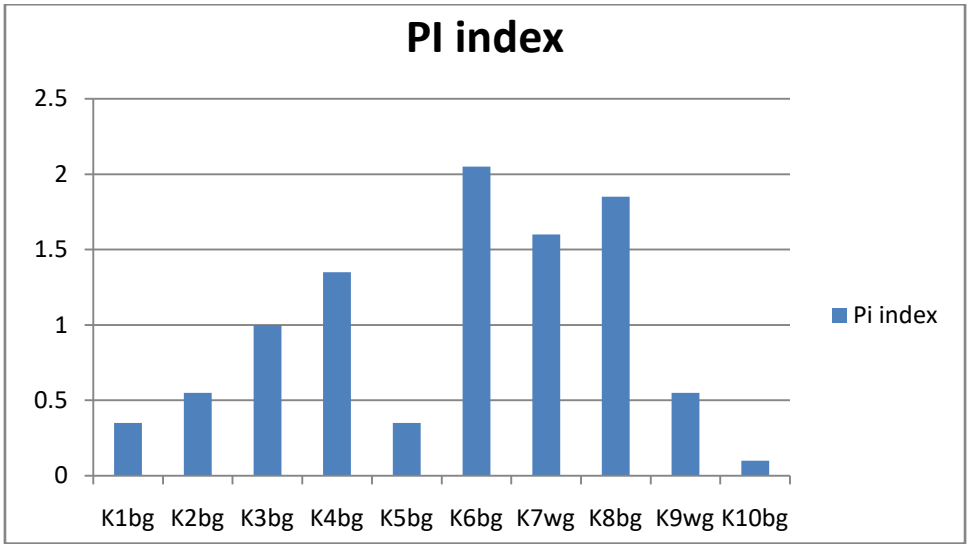

Figure 12: PI index for Bayankara area

PI index calculated for Badariya shows that only two locations have PI index > 1; this suggested that the locations B1tg and B2bg are polluted of manganese ion, thus, not fit for drinking purpose (Fig. 13)

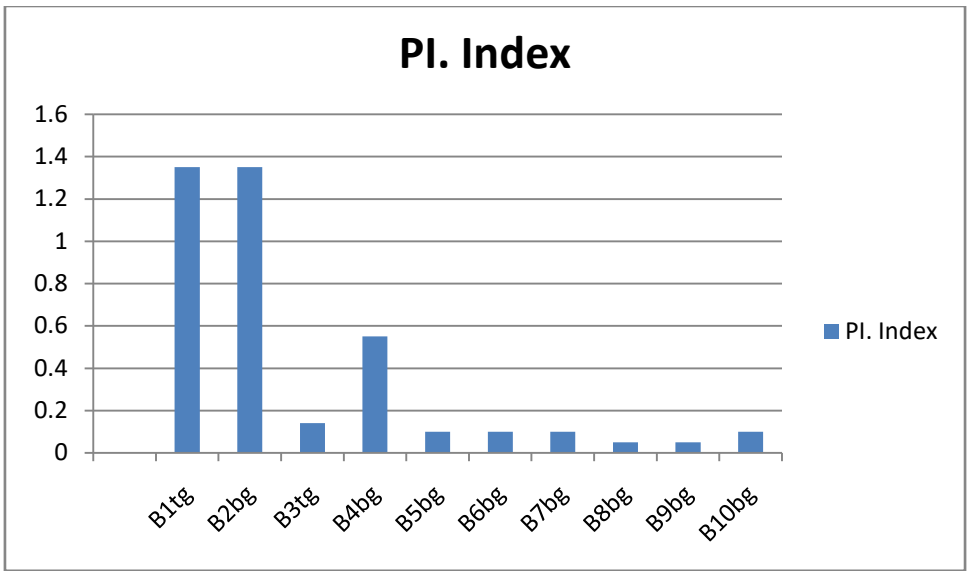

Figure 13: PI index for Badariya area

The presence of high concentration of Mn ion in the groundwater at Bayankara and Badariya may likely be from weathering of groundwater reaction with the sandstone aquifer rich in manganese minerals. It is also most likely to be due to environmental factors such as drainage or leaching from sewage dumps that litter the environment, couple with geological structures such as fractures, fault and joints that act as conduit pipes for transmission of leached manganese ions from sewages and landfills; thereby contaminated the local groundwater system. The intake of excess Mn ion from water could lead to liver damage and other health hazard.

The phosphorous anomalous values recorded in the 3 locations could result from decomposition of the aquifer system with production phosphorous if the aquifer is rich in it. It may as well be due to decaying sewages resulting from poor environmental sanitation. The source of phosphorous could be anthropogenic in nature due to application of chemical fertilizers to the farms, especially fertilizers that are rich in phosphates. The leached phosphorous percolate easily and readily into the groundwater as a result of peculiar structural features of the study areas which permit rapid percolation into the subsurface (Ola-Buraimo *et al.*, 2019).

Crops harvested from phosphate fertilizers fed on animals could as well increase the amount of phosphorous leached into the groundwater during rainfall as a result of application of manures derived

from animal feces in addition to phosphate fertilizer. This situation will rather compound and increase the concentration of phosphorous in the groundwater system. There is also possibility of deriving phosphorous from detergents. Therefore, one of the best ways to curb excess concentration of phosphorous in groundwater is by avoiding over-fertilization of the farms and proper improvement in environmental sanitation.

High concentration of ammonia ions was recorded in all the 3 locations studied. This was attributed to contamination by sewage water or as a result of leaching of manure of chemical fertilizers applied to farms in the areas. The trends in average concentration of phosphate and ammonia ions tend to suggest the effect of environmental sanitation and agricultural activities in the areas. Bayankara is most affected with average contamination values of relatively high concentration of PO_4 ion and lowest concentration of NH_4 ion to be 0.81mg/l and 3.7mg/l respectively; Bayankara exhibits relatively lower concentration of PO_4 ion and highest concentration of NH_4 ion to be 0.75mg/l and 4.0mg/l respectively, while Old Town shows highest concentration of PO_4 ion and moderate concentration of NH_4 ion containing 0.87mg/l and 3.8mg/l respectively. However, WHO (1986), stated that ammonia has a toxic effects on human only if the intake is higher than the capacity to detoxify, at a dose of more than 100mg/kg of body weight per day, it influences metabolism by shifting the acid-base equilibrium, disturbing the glucose tolerance equilibrium, and reducing the tissue sensitivity to insulin.

IX. Conclusion

Thirty water samples from 3 locations in Birnin kebbi, northwestern Nigeria were analyzed for geochemical study to determine water quality for drinking.

The results show that all the cations Na, K, Ca, Mg, Fe, Cu, and Zn ions from the 3 locations have values far less than maximum limit recommended by WHO except Mn ion that exhibits average concentration values in Bayankara 0.39mg/l, Badariya 0.16mg/l greater than 0.05mg/l tolerable limit by WHO standard. However, Old Town area has Mn ion values within the recommended limit. The PI index on manganese ion show that Bayankara is more polluted than Badariya probably due to unhygienic conditions of the areas and possibly due to dissolution of manganese mineral present in the sandstone aquifer.

The anions analyzed Cl, F, NO_3 and SO_4 have ion concentrations within the limits of WHO recommended for drinking water with the exception of NH_4 and PO_4 ion concentration values that are high in the 3 locations; showing values greater than 0.5mg/l for NH_4 and 0.3mg/l for PO_4. The contaminants might have resulted from anthropogenic means including sewage leaching and excessive application of leached fertilizer and manure. The pollutants migrated through tectonic and sedimentary structures which serve as conduit pipes for rapid transmission to groundwater system in the study areas.

Acknowledgements

The authors are grateful to the Federal University Birnin Kebbi, Nigeria for the opportunity given to carry out this research project through the sponsorship assistance from Tertiary Educational Trust Fund (TETFUND; Internal Based Research of the University). We are as well grateful to local people, private borehole owners and Kebbi State Water Cooperation at Dukku for permitting us to collect water from their sources for the study. We as well acknowledge the contribution of Benemaikwu D. O. of Department of Microbiology, Kebbi State University of Science and Technology, Aliero, Kebbi State, Nigeria in collection of water samples and assisting us to communicate with the locals in Hausa language.

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Cartographie Des Reseaux De Fractures De La Region De Gagnoa (Centre-Ouest De La Cote D'ivoire)

By Oscar Zahibo Onetie, Assoué Kouakou Sylvestre Kouadio, Adama Coulibaly, Kotchi Rodrigue Orou, Marie Rosine Fossou & Derving Baka

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Abstract- Characterisation of the fractures network precambrian basement Gagnoa area (Central West Ivory Coast) Located in the central-western part of Côte d'Ivoire, the Gagnoa region consists of sedimentary volcano and granitoid formations with developed fracturing. The objective of this study is to map the fracture network of the Precambrian basement of Gagnoa using Landsat-7 ETM+ satellite images and to characterize it from a statistical point of view. The raw satellite images were processed to enhance linear features considered to be fractures. The lineament map obtained after processing is very dense and contains 3,010 lineaments of varying sizes and orientations. The validation of the different linear structures was done on the basis of geophysical studies and the hydrographic map of the study area. The distribution of fracture orientations shows some fracture heterogeneity in the region. The statistical analysis performed on this fracture network shows that the distribution of fracture lengths follows a power law with a characteristic coefficient = 2.756, reflecting the advanced stage of fracture development. All the results contribute to a better knowledge of the fracture networks and groundwater functioning in the Gagnoa region. Translated with www.DeepL.com/Translator (free version).

Keywords: remote sensing, fractures network, geophysic, hydrographic statistics, ivory coast.

GJSFR-H Classification: FOR Code: 040699

CARTOGRAPHIEDESRESEAUXDEFRACTURESDELAREGIONDEGAGNOACENTREOUESTDELACOTEDIVOIRE

Strictly as per the compliance and regulations of:

Cartographie Des Reseaux De Fractures De La Region De Gagnoa (Centre-Ouest De La Cote D'ivoire)

Oscar Zahibo Onetie [α], Assoué Kouakou Sylvestre Kouadio [σ], Adama Coulibaly [ρ], Kotchi Rodrigue Orou [ω], Marie Rosine Fossou [¥] & Derving Baka [§]

Résumé- Localisée au Centre-Ouest de la Côte d'Ivoire, la région de Gagnoa est constituée de formations volcano sédimentaires et de granitoïdes avec une fracturation développée. La présente étude a pour objectif de cartographier le réseau de fractures du socle précambrien de Gagnoa à l'aide des images satellitaires Landsat-7 ETM+ et de le caractériser d'un point de vue statistiques. Les images satellitaires brutes ont fait l'objet de traitements de sorte à rehausser des éléments linéaires considérés comme fractures. La carte de linéaments obtenue après les traitements est très dense et comporte 3 010 linéaments de tailles et d'orientations variables. La validation des différentes structures linéaires a été faite sur la base d'études géophysiques et de la carte hydrographique de la zone d'étude. La distribution des orientations de fractures montre *une certaine hétérogénéité de la fracturation* dans la région. L'analyse statistique réalisée sur ce réseau de fractures montre que la distribution des longueurs de fractures obéit à une loi puissance avec un coefficient caractéristique $\alpha = 2{,}756$, témoignant du stade de développement avancé de la fracturation. L'ensemble des résultats contribue à une meilleure connaissance des réseaux de fractures et du fonctionnement des eaux souterraines de la région de Gagnoa.

Mots clés: télédétection, fracturation, géophysique, hydrographique, statistique, côte d'ivoire.

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I. Introduction

La structure des aquifères en zone de socle cristallin et métamorphique est très complexe. L'étude des réseaux de fractures est fondamentale pour la recherche en eaux souterraines car ils constituent les principaux chemins des écoulements souterrains. En effet, l'essentiel des ressources en eau se trouve dans les aquifères fracturés (Biémi, 1992; Kouamé, 1999; Lasm, 2000). Elle est également importante en ce qui concerne la recherche des sources d'énergie et des sites d'enfouissement de déchets nucléaires (Neretnieks et al. 1993 ; Dershowitz, et al. 1991).

De nombreux travaux (Krishnamurthy et al., 1996; Lloyd, 1999; Jackson, 2002) ont mis en evidence l'importance de la télédétection dans les investigations hydrogéologiques. Il a été montré que les images satellitaires contiennent des accidents géologiques qui ont un lien direct avec le débit des eaux souterraines (Kresic, 1994). En Côte d'Ivoire, les travaux de Biémi (1992), Savané et al. (1993), Savané (1997), Kouamé (1999), Jourda (2005) et Jourda et al. (2006) ont mis en évidence la relation entre les données de télédétection et les ressources en eaux souterraines dans les roches de socle. La télédétection par ces diverses méthodes de prétraitement et de traitement se présente comme un outil préférentiel pour une meilleure cartographie des réseaux de fractures. Elle permet d'étudier de vastes champs géographiques par sa vision synoptique.

Depuis les années 2000, le Centre-Ouest de la Côte d'Ivoire se trouve dans une situation de stress hydrique due au boom démographique. Cette situation sera accentuée par le développement d'activité minière exposant les ressources eaux à la pollution. De ce fait des études hydrogéologiques récentes ont été menées

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dans des régions voisines de la zone d'étude par de nombreux auteurs (Yao, 2009; Sorokoby et *al.,* 2010; Baka, 2012; De Lasme, 2013) afin d'appréhender le fonctionnement des réservoirs fracturés. C'est dans cette même optique que ce travail a été initié. Il va consister à cartographier le réseau de fractures, de le caractériser à partir de méthodes statistiques et d'en évaluer sa densité. Cette étude permettra une meilleure connaissance de la géométrie du milieu fracturé de la région de Gagnoa.

II. Cadre D'étude ET Contexte Géologique

Située au Centre-Ouest de la Côte d'Ivoire, entre 5°40 et 6°10 de latitude Nord et entre 5°50 et 6°20 de la longitude Ouest, en domaine de socle, la région de Gagnoa couvre une superficie de 2 500 km^2 avec une population cosmopolite estimée à 897 117 habitants (Ins, 2015). Ce département est composé d'une pénéplaine légèrement ondulée, d'altitude moyenne de 220 m avec un relief est peu marqué.

Le socle précambrien de Côte d'Ivoire est constitué de deux grands ensembles. L'archéen et le protérozoïque séparés par la faille majeure du Sassandra de direction N-S dont l'histoire est complexe (Camil, 1984; Djro, 1998). L'histoire géologique de la région de Gagnoa s'inscrit dans celle du domaine protérozoïque. Selon Géomines (1982), les différentes unités géologiques peuvent être subdivisées en deux entités (Figure 1):

- les volcano-sédimentaires représentées par des amphibolites qui s'apparenteraient à des tuffs dacitiques et des schistes chloriteux, sériciteux de couleur grise à verte;
- les granitoïdes constitués en grande partie par des granites à deux micas et les granodiorites.

Au plan hydrogéologique, on y rencontre les aquifères des niveaux supérieurs (altérites), des fissures (horizon fissuré) et de failles.

Selon la carte de Tagini (1971), la région de Gagnoa ne présente pas assez de données structurales. Néanmoins il a été identifié quelques failles orientées NO-SE dans le Nord-ouest.

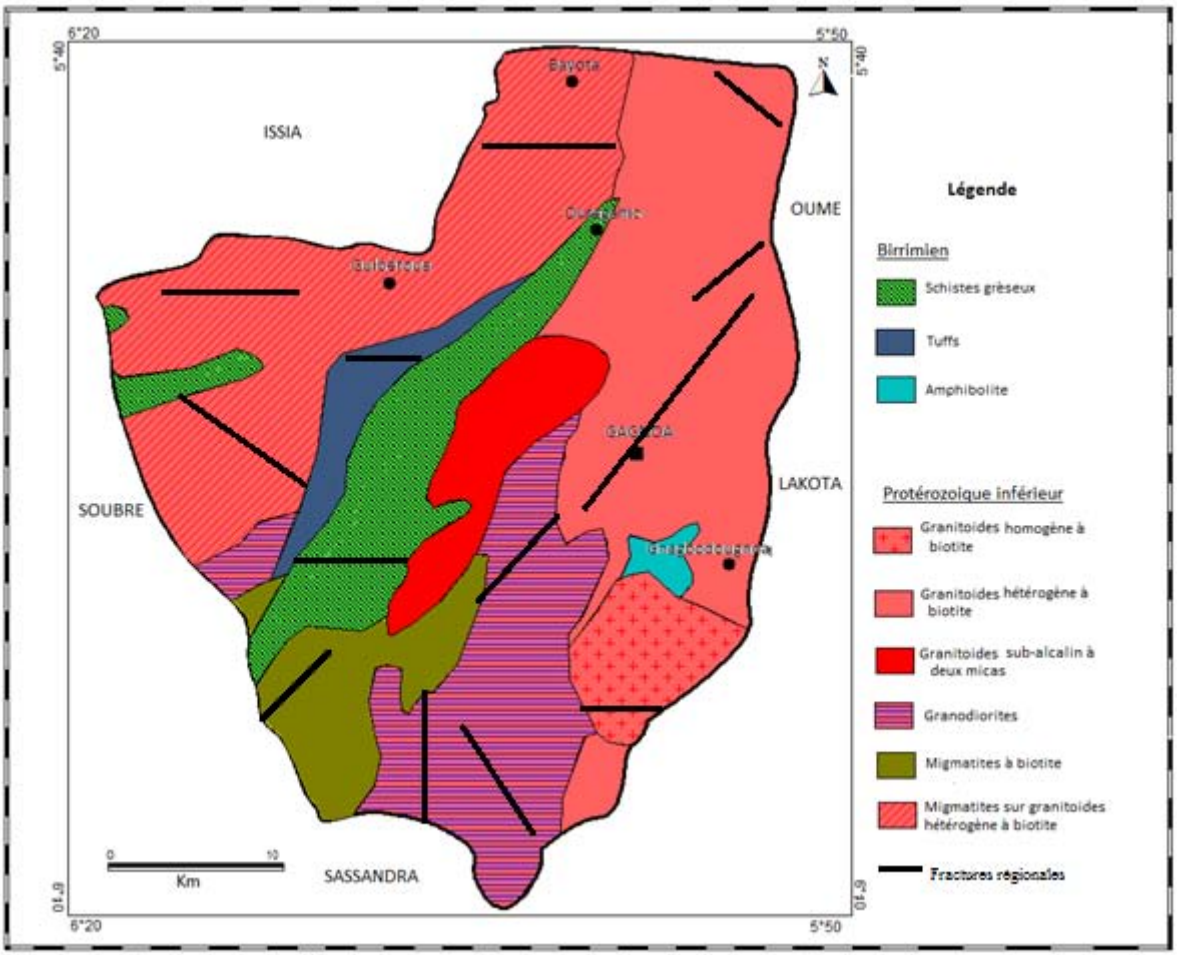

Figure 1: Carte géologique de la région de Gagnoa modifiée (Papon et Lemarchand, 1973)

III. Matériel ET Méthodes

a) Données

Cette étude a nécessité l'utilisation de plusieurs types de données dont les cartes géologiques et topographiques à l'échelle 1/200 000 des degrés carrés Gagnoa, Daloa, Grand-Lahou et Soubré de Géomines (1982); les images satellitaires ETM+ de Landsat-7 (197-55 et 197-56) ont été utilisées pour la cartographie du réseau linéamentaire; les données géophysiques constituées de profils de résistivité issues de 57 trainés électriques pour la validation de la carte de fracturation. Ces images satellitaires ont été choisies du fait de leurs caractéristiques spectrales et spatiales permettant une bonne cartographie structurale à petite échelle (Youan Ta et *al*, 2008). Les images Landsat sont composées de sept bandes (1, 2, 3, 4, 5, 6, 7) de résolution spatiale 30×30 m.

b) Méthodologie

i. *Cartographie des linéaments*

La cartographie des linéaments a été possible grâce aux différents traitements appliqués aux images satellitaires ETM+ de Landsat-7 (197-55 et 197-56) corrigés et mosaïquées. La méthodologie de traitement d'images pour l'extraction des linéaments suit l'ordre suivant l'analyse en composante principale (ACP), la combinaison d'images (addition et rapports de bandes), les compositions colorées et le filtrage spatial (filtre Sobel).

- *Analyse en composante principale*

L'analyse en composante permet de rehausser les images et de réduire le nombre de bandes à traiter en comprimant les informations selon une hiérarchie (Bonn et *al*., 1992). L'analyse en composantes principales a été réalisée sur sept canaux à savoir ETM^+1, ETM^+2, ETM^+3, ETM^+4, ETM^+5, ETM^+6, ETM^+7. Le résultat des trois premières composantes ACP1, ACP2 et ACP3 donne respectivement 81,93 ; 10,44 et 3,26% des informations. Il en résulte que 95,63% des informations sont comprises dans les trois premières composantes. La technique de l'étalement linéaire a ensuite été appliquée à ces néo-canaux pour une amélioration du contraste.

- *Combinaisons d'images et compositions colorées*

Plusieurs opérations ont été exécutées en particulier les combinaisons d'images. Les linéaments régionaux sont relevés par la combinaison des canaux (ETM^+7/ ETM^+6), (ETM^+4/ ETM^+6) permettant de mettre en évidence les fractures d'ordres kilométriques et plurikilométriques. Ces linéaments sont également mis en évidence par le rapport de bandes (ETM^+6- ETM^+7)/ (ETM^+6+ ETM^+7) selon Kouamé (1999). La composition colorée facilite la perception visuelle d'images en attribuant à chacune d'elles une des couleurs de base : Rouge (R), Verte (V) et Bleu (B).

- *Techniques de filtrage spatial*

Dans la présente étude, les filtres directionnels de Sobel (de type 7×7) ont été utilisés pour identifier les linéaments. Ils accentuent les discontinuités lithologiques et structurales dans les quatre directions N-S; NE-SW; NW- SE; E- W (Tableau I). Les discontinuités lithologiques et structurales correspondantes à des linéaments structuraux ont été relevées manuellement suivant une analyse visuelle à l'écran.

Tableau I: Filtres directionnels 7×7 de Sobel (Kouamé, 1999)

1	2	1	2	1	1	1
1	1	2	3	2	1	1
1	1	3	4	3	2	1
0	0	0	0	0	0	0
-1	-2	-3	-4	-3	-2	-1
-1	-1	-2	-3	-2	-1	-1
-1	-1	-1	-2	-1	-1	-1

Direction N-S

-1	-1	-1	0	1	1	1
-1	-1	-2	0	2	1	1
-1	-2	-3	0	3	2	1
-2	-3	-4	0	4	3	2
-1	-2	-3	0	3	2	1
-1	-1	-2	0	2	1	1
-1	-1	-1	0	1	1	1

Direction E-W

0	1	1	1	1	1	2
-1	0	2	2	2	3	1
-1	-2	0	3	4	2	1
-1	-2	-3	0	3	2	1
-1	-2	-4	-3	0	2	1
-1	-3	-2	-2	-2	0	1
-2	-1	-1	-1	-1	-1	0

Direction NE-SW

2	1	1	1	1	1	0
1	3	2	2	2	0	-1
1	2	4	3	0	-2	-1
1	2	3	0	-3	-2	-1
1	2	0	-3	-4	-2	-1
1	0	-2	-2	-2	-3	-1
0	-1	-1	-1	-1	-1	-2

Direction NE-SE

- *Validation de la carte linéamentaire*

Après la cartographie des linéaments, une validation de celle-ci est nécessaire car les traitements d'images satellitaires se heurtent régulièrement au problème de fiabilité. Cette validation se fait par superposition de cette carte sur d'autres cartes ou sources de données. Les épaisses couches d'altérites et la forte végétation existantes sur la zone d'étude n'a pas permis l'observation de figures caractéristiques des linéaments sur affleurements. Une étude de terrain basée sur une étude géophysique a été initiée pour confirmer l'existence des segments observés par imagerie satellitaire. Les profils électriques obtenus après cette étude ont permis d'identifié des linéaments. Ces linéaments se caractérise sur les profils électriques issues du trainé par une variation latérale significative des résistivités (figure 2). La méthode de détermination des directions des linéaments décelés sur les profils électriques a été inspirée des travaux de Coulibaly (2014).

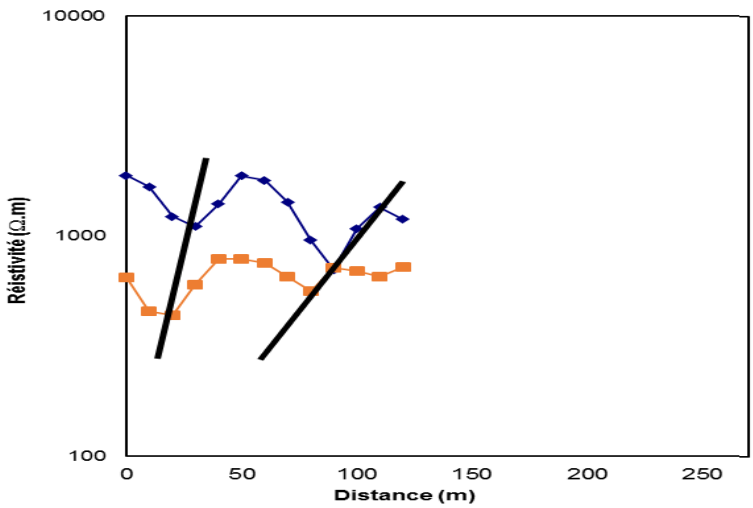

Figure 2: Tracé de linéament dans le village de Dalilié

La carte du réseau hydrographique a également servi de support pour la validation de la carte de fracturation de Gagnoa. La démarche a consisté à comparer les orientations des segments de cours d'eau rectilignes, à celles des linéaments cartographiés. Ce principe de base épouse celui de Julian *et al*., (1988). Plusieurs auteurs (Lasm et Razack, 2001 ; Dupouy *et al*., 2011 ; Tahiri, 2013) ont également montré l'existence de la corrélation entre la fracturation et l'hydrographie.

c) Analyse statistique de la fracturation

L'analyse statistique de la fracturation a été réalisée afin de caractériser les paramètres de la fracturation notamment l'orientation, le nombre, et la longueur des fractures. Cette étude statistique a été conduite sur le réseau de linéaments cartographié.

- *Intensité de la fracturation*

L'intensité de la fracturation est exprimée en nombre, et en longueurs cumulées de fractures par maille. En effet, la zone d'étude a été subdivisée en maille carrées de 5×5 km^2 et à l'intérieur de chaque maille, le nombre et la longueur cumulée des fractures ont été déterminés. Par la suite, une étude de régression linéaire est effectuée entre l'intensité en nombre de fractures (NF) et l'intensité en longueur cumulée (LC) par maille. Si la corrélation est établie, l'un ou l'autre de ces paramètres pourra être utilisé pour exprimer l'intensité de fracturation.

- *Ajustement des longueurs de fractures*

Dans cette étude, longueurs de fractures ont été ajustées la loi puissance. Cette loi reste valide pour un intervalle de longueur déterminé (Odling *et al.*, 1999, Darcel, 2002). L'ajustement à la loi de puissance consiste à reporter dans un diagramme bi-logarithmique la distribution de fréquences des longueurs. Si les points s'alignent suivant une droite, la distribution suit alors une loi de puissance d'expression (Bodin et Razack, 1999). :

$$N(x) = a \times x^{-\alpha} \quad (1)$$

avec:
x: centre de classe de la variable (par exemple la longueur des fractures);
N: fréquence de classes;
a: coefficient de proportionnalité;
α: exposant caractéristique de la loi puissance.

IV. Résultats

Le traitement des images satellitaires a permis de cartographier les linéaments structuraux de la région de Gagnoa (figure 3). La carte des linéaments comporte de nombreux linéaments de longueurs variables et d'orientations diverses. La taille de ces linéaments s'échelonne sur plus ordre de grandeur.

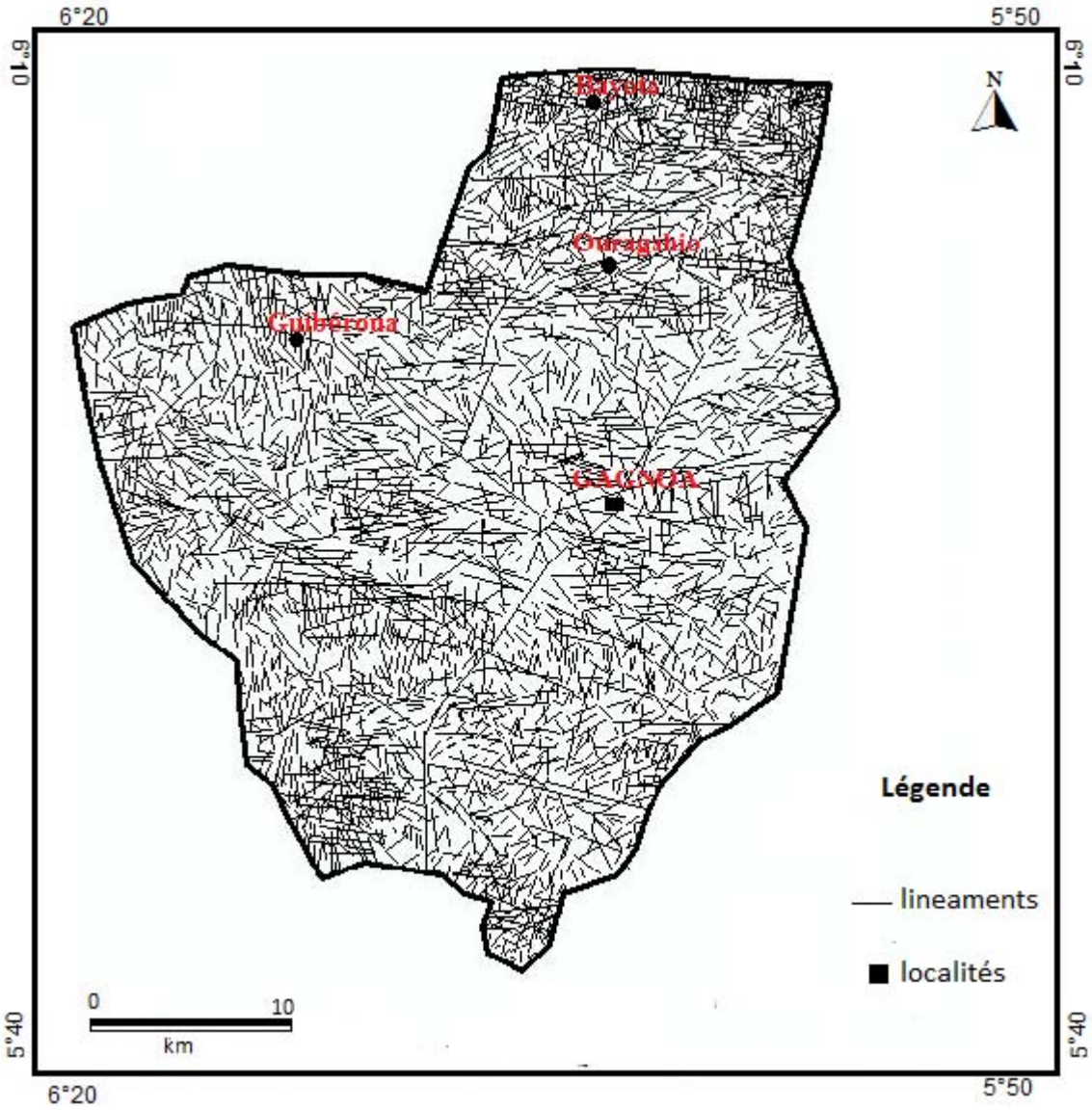

Figure 3: Carte linéamentaire de la région de Gagnoa établit à partir d'une image landsat ETM+.

- *Longueur des linéaments détaillés*

La longueur des linéaments varie entre 0,36 et 22,4 km avec une moyenne de 2,4 km soit sur deux ordres de grandeur soulignant plus ou moins l'hétérogénéité du milieu. La valeur du coefficient de variation (Cv = 120%) supérieur à 100% indique une certaine dispersion des données. A l'examen des données des longueurs de linéaments, il ressort que les linéaments de petites tailles sont plus nombreux que ceux de grande taille. En effet, 92,09 % des linéaments ont une taille inférieure ou égale à 5 km (figure 3).

Tableau II: Statistique des longueurs de linéaments

	Effectif	Minimum	Maximum	Moyenne	CV
Longueur de linéaments (km)	3 010	0,36	22,4	2,4	120

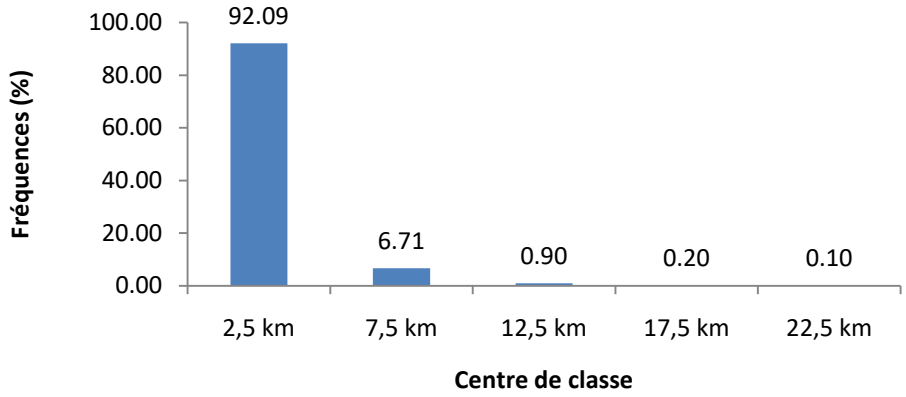

Figure 4: Histogramme de la distribution des longueurs de linéaments par classes

La figure 4 présente la distribution des longueurs de linéaments dans un diagramme bi-logarithmique (le pas des classes est de 450 m). Nous pouvons remarquer sur ce graphique que seule une partie de la courbe ($1{,}35 \leq \ell \leq 12{,}5$ km) présente un comportement linéaire sur laquelle il est possible d'ajuster une loi de puissance. Cette loi de puissance à pour expression:

$$N(\ell) = 1242 \times \ell^{-2{,}756} \quad (3)$$

$R^2 = 0{,}956$ (R^2 calculé pour les longueurs comprises dans l'intervalle $1{,}35 \leq \ell \leq 12{,}5$ km).
où N désigne l'effectif des linéaments et ℓ désigne la longueur des linéaments.

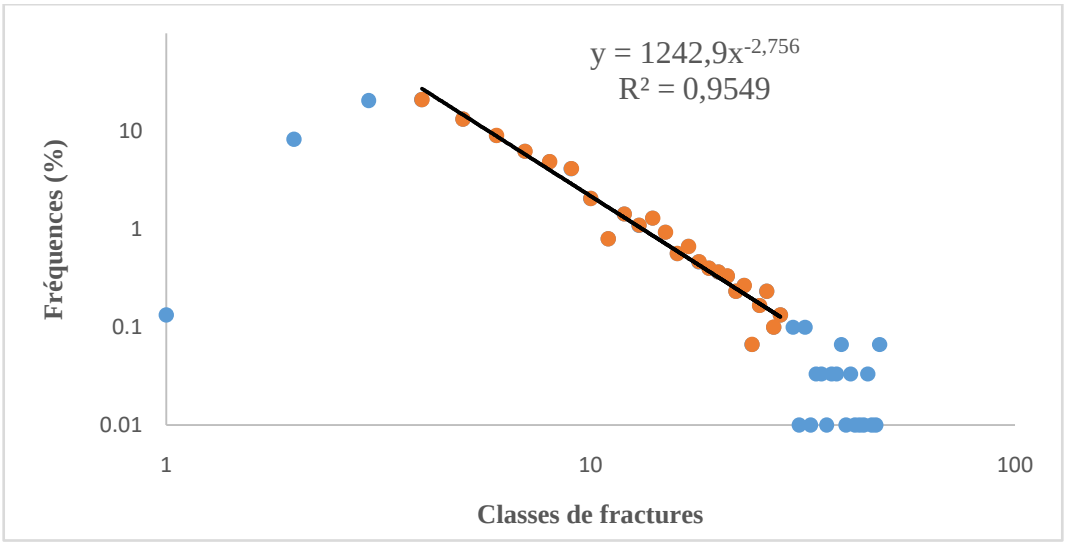

Figure 5: Ajustement de la distribution des longueurs de fractures à une loi puissance

Le coefficient caractéristique de la loi puissance est de $\alpha = 2{,}756$ pour des longueurs de fractures comprises entre 1,35 et 12,5 km. Ce résultat témoigne de du stade de développement avancé du réseau de linéaments de la région de Gagnoa.

La connectivité du réseau dans cette partie du pays est assurée aussi bien par les petits et longs linéaments. La distribution des longueurs de linéaments de la région de Gagnoa obéit à une loi puissance pour des longueurs comprises entre 1,35 et 12,5 km. Pour les longueurs de fractures inférieures à 1,35 km, on est confronté à un problème de sous échantillonnage qui ne permet pas de rendre compte des petites fractures. La loi de puissance ne rend pas toutefois compte des

petites fractures. Pour les valeurs inférieures à 12,5 km, on s'éloigne très significativement de la droite linéaire théorique mettant en évidence les limites de résolution avec la rupture de pente.

- *Distribution des orientations des fractures*

La distribution des orientations des fractures est illustrée par la figure 6. Sur cette rosace, seule la famille de fractures la direction N0-10 se démarque de l'ensemble des familles avec une fréquence en nombre de 15%. Elle constitue la famille majoritaire ou principale de fracturation de la région. Après elle, apparaissent secondairement les familles N90-100 et N10-20 qui constituent les familles de fractures secondaires avec respectivement des fréquences de 9 % et de 7%. Les autres familles présentent des fréquences inférieures à 6%. Ce résultat témoigne d'une certaine hétérogénéité dans la distribution des orientations de fractures dans la région étudiée.

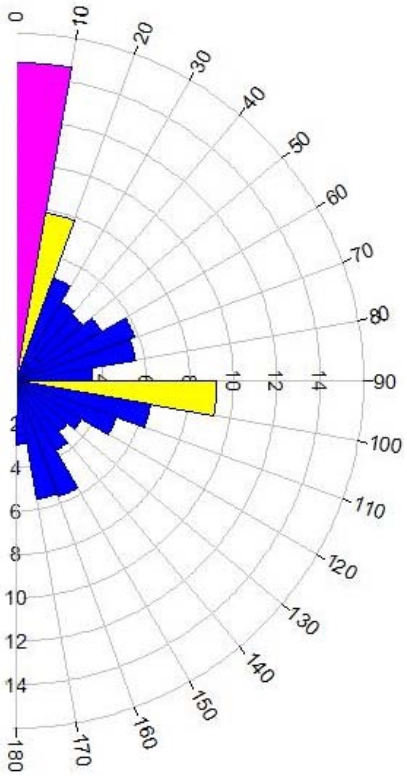

Figure 6: Rosace directionnelle de fréquence d'orientation de la linéation (N = 3010)

- *Validation du champ linéamentaire*

La rosace des brins du réseau hydrographique est illustrée à la figure 7b. La classe de fractures N00-10 et N90-100 apparaissent les plus prédominants. Les autres classes présentent des fréquences inférieures ou égales à 6%. Ce résultat s'apparente à celui du réseau de linéament extrait des images satellites. Les réseaux de linéament et hydrographique présente le même comportement en ce qui concerne leur répartition sur l'espace étudié. Le données géophysiques donnent des résultats quelques peu différents compte tenu du nombre de fractures pris en compte comparativement au réseau de linéament et aussi de l'échelle d'investigation (Figure 7a). Cependant on peut noter quelques similitudes. En effet on retrouve les familles NS (N170-180) et N90-100. En plus de ces familles, il apparait aussi la famille N130-140. De tout ce qui précède, nous pouvons conclure que les linéaments cartographiés par imagerie satellitaire ont une valeur de fracturation et peuvent être considérés comme des fractures.

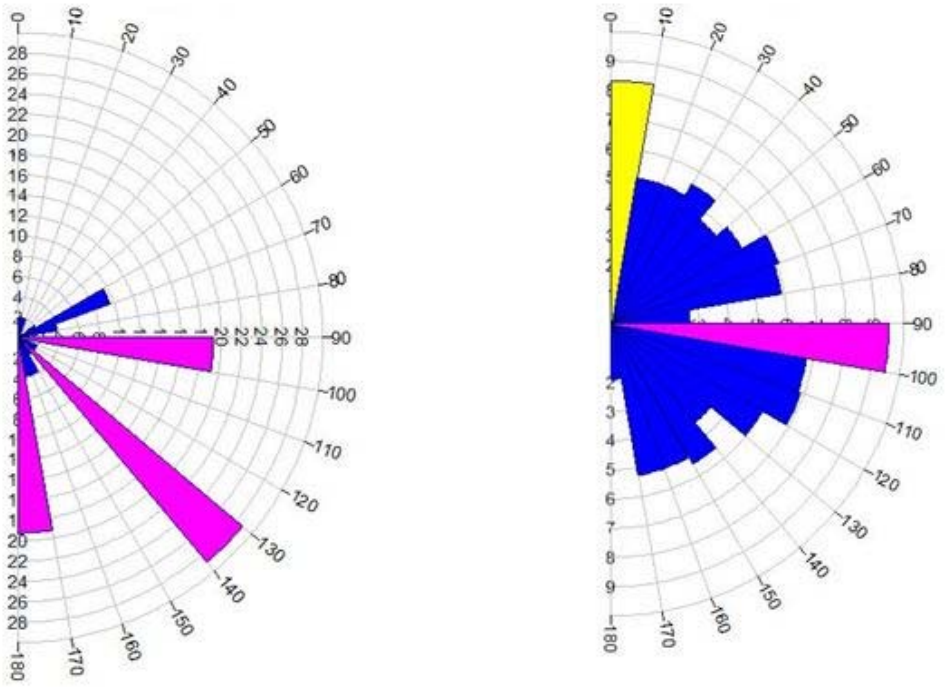

Figure 7: a) Rosace directionnelle des linéaments issues des études géophysiques (N= 51)
b) Rosace directionnelle des segments de cours d'eau rectiligne (N= 3320)

- *Intensité de la fracturation*

Les différentes valeurs de l'intensité de la fracturation (en longueurs cumulé de fractures et en nombre de fractures) sont résumées dans le tableau III.

Tableau III: Statistiques élémentaires de la densité de fracturation

Densité de fracturation	Maximum	Minimum	Moyenne
longueurs cumulées de fracture par maille (km/km^2)	36,91	0,07	23,01
nombre de fractures par maille (fractures /km^2)	38	1	20,39

La relation entre la densité en longueur cumulée (LC) et en nombre (NB) est analysée au niveau de la figure 8. Les différents points forment un nuage de points dans le diagramme arithmétique avec une certaine tendance mettant en évidence une possible relation entre ces deux paramètres. La relation est de type linéaire positive et est définie par l'équation des moindres carrées :

$$LC = 1{,}912 + 1{,}034\ NB \qquad (2)$$

avec un coefficient de détermination R^2 de 0,7494, soit un coefficient de corrélation de R= 0,865. Cette valeur indique que le test statistique est satisfaisant. Ces deux paramètres étant donc corrélés ainsi l'un ou l'autre pourrait être utilisé pour exprimer l'intensité de la fracturation.

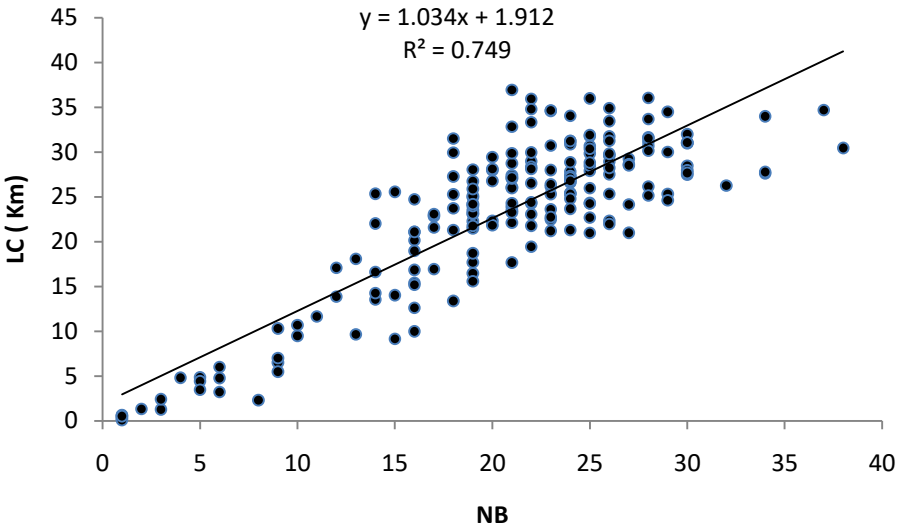

Figure 8: Corrélation entre intensité de fracturation en nombre de fractures (NB) et en longueurs cumulées (LC)

La figure 9 présente la distribution spatiale de l'intensité de la fracturation en longueurs cumulées. La densité varie d'une maille à l'autre sur ces deux cartes. Cette variabilité spatiale témoigne d'une certaine hétérogénéité au niveau de la fracturation de la zone d'étude. L'observation des deux cartes montre que la région est fortement fracturée. Les zones de fortes densités de fracturation occupent plus de la moitié de la zone d'étude. Sur la carte de densité en longueurs cumulées (Figure 45), les zones de fortes densités, se rencontrent de la partie centrale et au nord avec une régression de la densité des bordures vers le centre de la zone. Ces zones représentent 60% de la région. La zone de très forte fracturation au nord est matérialisée par la présence d'un cours d'eau appelé le Nahouri.

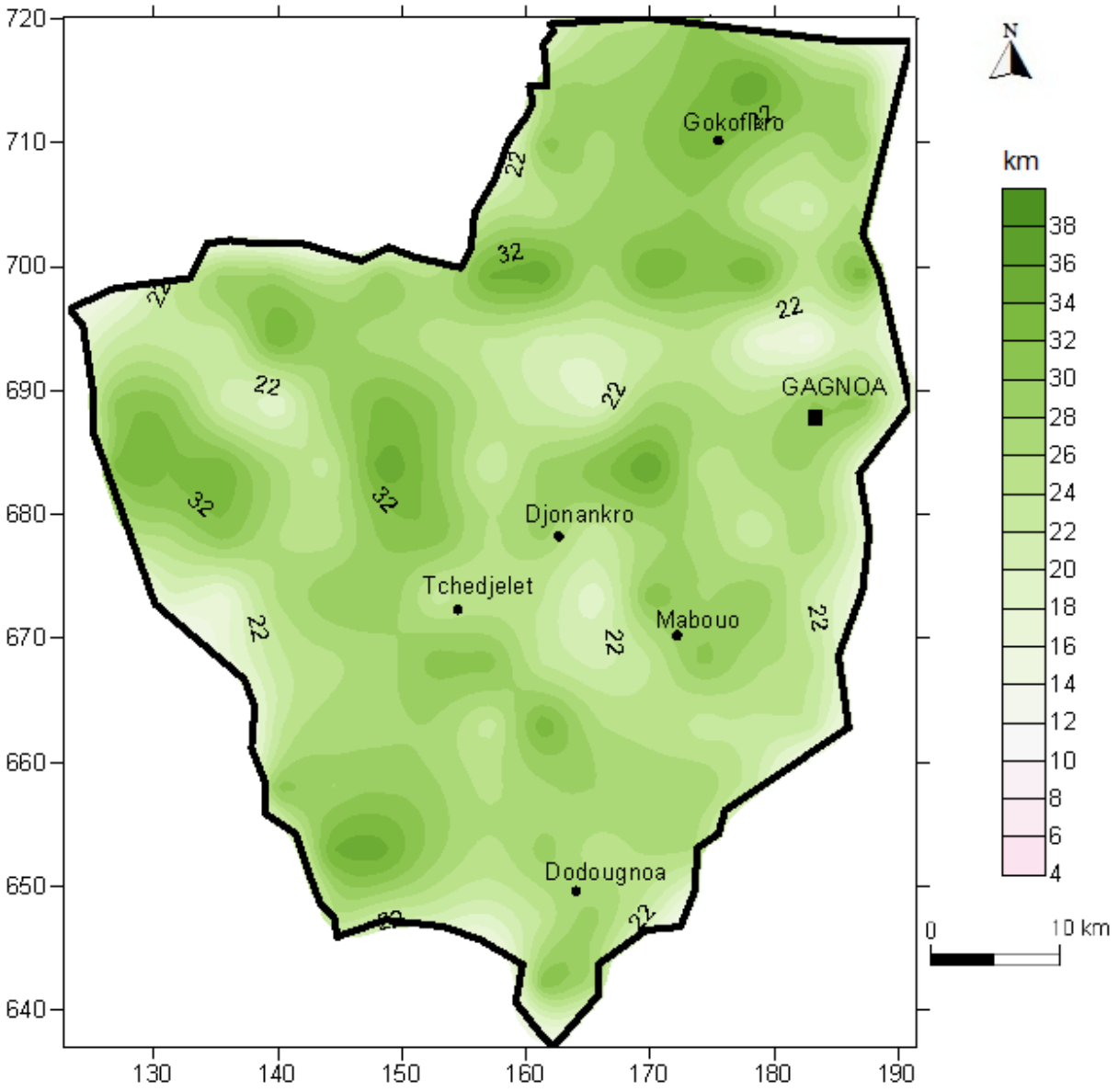

Figure 9: Carte de densité de fracturation en longueurs cumulées (LC) (maille 5×5 km)

- *Relation entre la fracturation et la pétrographie*

La correspondance entre facturation et la pétrographie de la zone d'étude est illustrée à la figure 10. Cette figure montre que les zones de forte intensité de fracturation coïncidente dans la plupart des cas avec les formations volcano sédimentaires (schiste et tuf). Néanmoins des zones de fortes densités de fracturation sont rencontrées dans les granitoïdes.

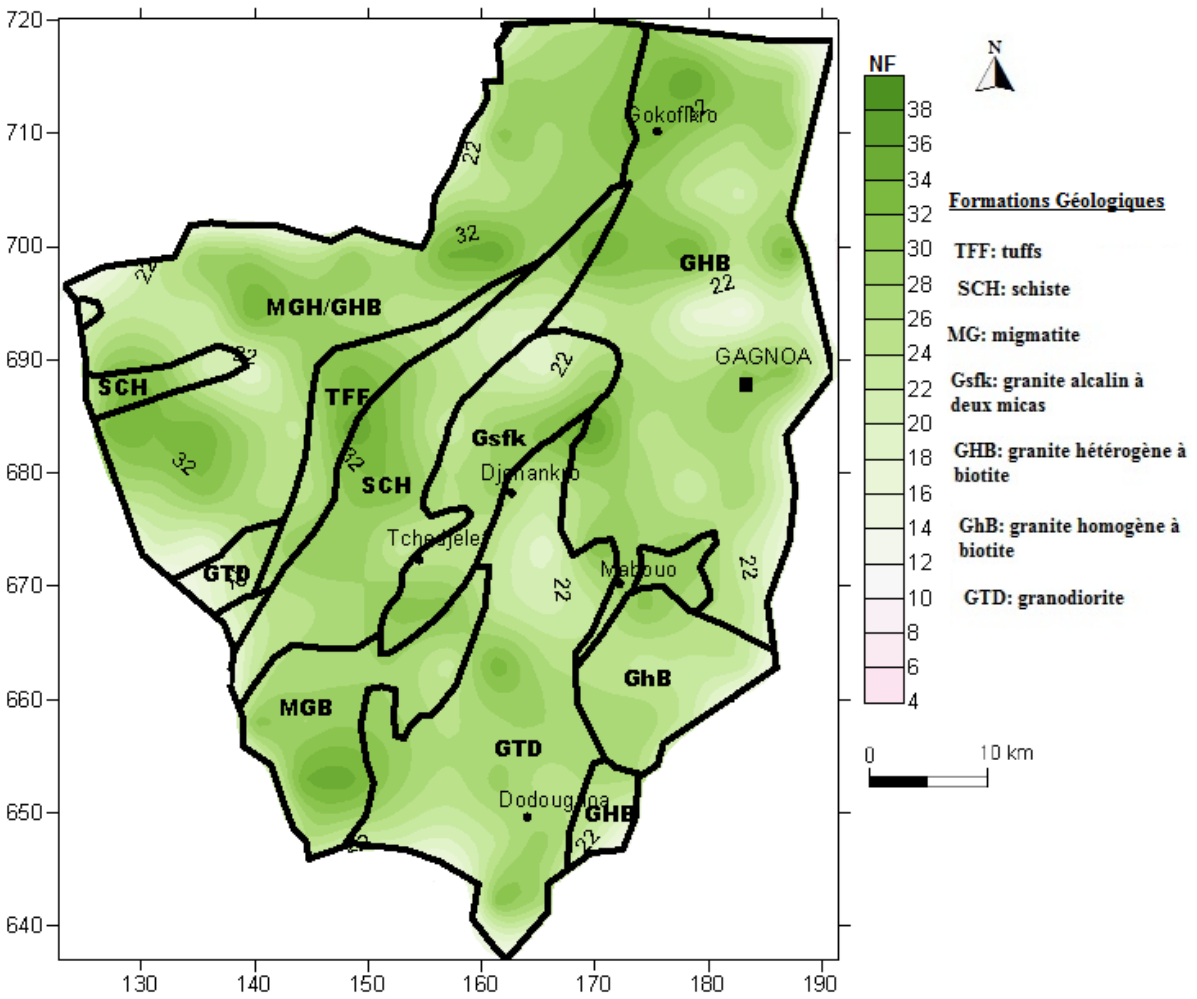

Figure 10: Densité de fracturation exprimée en nombre de fractures et des grands ensembles géologiques

V. Discussion

La caractérisation de la géométrie des fractures a fait l'objet de nombreuses études (Chiles, 1989; Biémi, 1992; Gillespie *et al.*, 1993; Bodin et Razack, 1999; Darcel *et al.*, 2003 ; Razack et Lasm, 2006 ; Youan Ta *et al.*, 2008; Baka, 2012). Ces études ont permis une meilleure connaissance des milieux fracturés. Des études menées dans les régions proches de la zone étude par Yao (2009), Sorokoby et *al.* (2010), Baka (2012) et De Lasme (2013) où ont été cartographiées plusieurs centaines de fractures dans les régions de Soubré, de San Pédro et d'Oumé. Dans les régions de Soubré et de San Pédro, les directions préférentielles de fracturation enregistrées sont les directions de N00-10 et N90-100. Dans la région d'Oumé, Baka, 2012 n'a pas trouvé de direction préférentielle néanmoins la direction N90-100 se démarquerait des autres directions de fracturation. Aussi, des travaux réalisés dans le degré carré de Grand-Lahou, situé au Sud de la zone d'étude, par Soro (2002) identifie 3 directions principales de fractures que sont N00-10, N90-100 et N40-50. Ainsi, les directions principales des fractures identifiées à Gagnoa sont similaires à celles relevées dans les zones voisines. Ce qui laisse suggérer que ces régions ont été affectées par une tectonique similaire ou même identique. Ces linéaments peuvent être assimilés par conséquent à des fractures. La distribution suivant la loi puissance des longueurs de fractures est en accord avec plusieurs travaux réalisés en Côte d'Ivoire; notamment ceux de Lasm (2000), Jourda (2005), Youan Ta (2008), Baka et *al*. (2012), De Lasme (2013). Cette distribution fait ressortir un effet de « troncation » dû à des petites fractures sous échantillonnée aux limites de résolution de détection et aux méthodes d'échantillonnage (Ackermann et *al.,* 2001; Bonnet et *al.,* 2001). L'exposant caractéristique de la loi de puissance est en accord avec les données de littératures comprises généralement entre 1 et 3 (Bodin et Razack, 1999; Lasm, 2000; Jourda, 2005; Baka, 2012). Selon De Dreuzy (2000), pour un réseau 2D l'exposant caractéristique de la loi puissance donne des renseignements sur la connectivité du réseau de fracture.

- $\alpha > 3$, la connectivité est contrôlée par les petites fractures et les règles de la théorie de la percolation s'appliquent;
- $\alpha < 2$, le rôle des petites fractures est négligeable et, en terme de connectivité, le système est similaire à une superposition de fractures infinies;
- $2 < \alpha < 3$, les longues et les petites fractures contrôlent à la fois la connectivité, qui est significativement dépendante de l'échelle.

Différents exposants caractéristiques obtenus dans diverses régions de la Côte d'Ivoire notamment par Lasm (2000), Youan Ta (2008), Yao (2009), Baka (2012), De Lasme (2013) respectivement à Man-Danané ($\alpha = 2{,}91$); à Bondoukou ($\alpha = 2{,}98$); à Soubré, ($\alpha = 2{,}61$); à Oumé, ($\alpha = 2{,}75$); à San Pedro, ($\alpha = 2{,}65$), montre que la connectivité du socle fracturé est contrôlée par les petites et longues fractures.

Bonnet et *al.* (2001) montre qu'il existe une relation entre la maturité d'un réseau de fractures et la loi d'ajustement. En effet, Les réseaux peu matures sont distribués suivant la loi exponentielle, alors que les réseaux plus matures suivent une loi puissance. Le stade de maturité ultime étant distribué suivant une loi log-normale. De ce fait le réseau de fracture de la zone d'étude est un réseau mature. Plusieurs auteurs (Engalenc, 1978; Kouadio, 2005a; Kouadio *et al.*, 2008) se sont intéressés à la relation liant la pétrographie à la fracturation. La présence de nombreux minéraux phyllosilicatés de biotites et de muscovites dans les granitoïdes seraient à l'origine des zones de forte intensité de fracturation. En effet, ces minéraux par altération sont à l'origine des fissures (Wyns *et al.*, 1999; Wyns *et al.*, 2004; Dewandel *et al.*, 2006; Koita, 2010). La structure lamellaire de ces minéraux crée des zones de moindre résistance dans la roche (Yacé, 2002).

VI. Conclusion

Le traitement et l'analyse d'images Landsat 7 ETM+ a permis de cartographier un réseau de fractures comportant 3 010 linéaments dans la région de Gagnoa. Les orientations préférentielles du réseau de fractures sont les directions N00-10 et N90- 100. Ces fractures ont une longueur variant de 0,36 à 22,4 km. L'ajustement des longueurs de fractures à la loi puissance est satisfaisant avec un coefficient révélant le caractère mature de la fracturation. L'estimation de la densité de fracturation en longueur cumulé et en nombre de fracture par maille montre une relation entre ces deux paramètres avec un coefficient de corrélation ($R^2 = 0{,}749$) satisfaisante. La distribution spatiale de la densité de fracturation montre diverses zones d'intenses fracturations dont le Nord et le Centre.

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Coupling of Rainfall Triggered Debris Flow Simulation in Parts of Bandarban, Bangladesh: An Earth Observation based Approach for Landslide Hazard Assessment

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Abstract- Debris flow modeling is process oriented approach in nature and considers avalanches, flows, falls and has become necessary to plan, manage and mitigate. There have numbers of empirical equations to depict kinematics of debris flow and scientific simulations. In the current study, the Rapid Mass Movements Software (RAMMS) has employed for natural flow modeling of displaced geophysical mass for parts of Rangamati area in Bangladesh. The digital elevation model (DEM) with 12.5m spatial resolution and supported by related secondary data, various geo-mechanical factors, cues from Voellmy rheological model are used as an important inputs for the model. The simulated result provide spatial variability of different geophysical parameters like pressure, momentum, velocity and height in the affected run-out zone. These outputs provides crucial information on real time landslide hazard mitigation and support to development of early warning systems.

Keywords: *debris flow, DEM, hazard, landslide and RAMMS.*

GJSFR-H Classification: *FOR Code: 961099*

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Md Moniruzzaman [α] & Shovan L. Chattoraj [σ]

Abstract- **Debris flow modeling is process oriented approach in nature and considers avalanches, flows, falls and has become necessary to plan, manage and mitigate. There have numbers of empirical equations to depict kinematics of debris flow and scientific simulations. In the current study, the Rapid Mass Movements Software (RAMMS) has employed for natural flow modeling of displaced geophysical mass for parts of Rangamati area in Bangladesh. The digital elevation model (DEM) with 12.5m spatial resolution and supported by related secondary data, various geo-mechanical factors, cues from Voellmy rheological model are used as an important inputs for the model. The simulated result provide spatial variability of different geophysical parameters like pressure, momentum, velocity and height in the affected run-out zone. These outputs provides crucial information on real time landslide hazard mitigation and support to development of early warning systems.**

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I. Introduction

Landslide is collapse of earth, rock or debris from mountain or hill cliff down a slope. And defined as costly interruption of functioning a society/community causing extensive human, economic, social, material and environmental losses that goes beyond the ability of affected community. Landslide is the most significant geological hazards that contribute to natural disasters in hilly trerain of Chittagong, Bangladesh due to triggering influences e.g. heavy rainstorms, earthquakes, cloudbursts, geo-engineering setting, population intensification, indiscriminate hill cutting, unauthorized settlements, unplanned human activities, deforestation etc. [1-9]. The landslide is resultant by the effects of gravity and landform from the sliding movement of rock, soil, and organic materials under [10]. Landslide has become a frequent phenomenon for parts of Chittagong which brutally affects life, livelihood and property of the inhabitants blooming on every day trip, tourism and agriculture [5,7,11]. Physiographically, 18% of Bangladesh is hilly area and more of floodplain [12]. It has been found that over 0.5 million insolvent people are living on the lethal foothills of Chittagong [13,14]. Nearly 235 people died due to landslides in several informal settlements during 1997 in Chittagong and its contiguous urban fringes [15].

Debris flows and debris rushes have become a major natural hazard process in hilly regions which are complex, gravity-driven, water and sediments with extreme moveable capacity [16-23]. Modeling debris flow is a dynamic research arena and can play substantial role in disaster mitigation and management [24-26]. In this study, evolved Rapid Mass Movements Software (RAMMS) as an art of mathematical simulation model to forecast motion of stirring mass declining naturally from relief area (head) to base area via 3D/2D. Digital elevation model (DEM), the Voellmy rheological inputs and secondary ground data i.e. geotechnical parameters are fundamental prerequisites for RAMMS [9, 27-31].

a) Study area

The study undertaken is mostly surrounded in Bandarban district and a small part of south-eastern Rangamati district. The study area is approximately in-between 92.230282 decimal degrees (dd) to 92.594080 dd east longitude and 22.211499 dd to 21.850400 dd north latitude (Figure-1). Both Bandarban and Rangamati are the two hill districts among there of Bangladesh. The Tahjindong (1280m) Mowdok Mual (1052m), and Keokradong (883m) are the height hill peaks of Bangladesh including newly reported Saka Haphong (1063.1424m). The Sangu River (also known as Sangpo or Shankha), Matamuhuri and Bakkhali are the major river in Bandarban district [32]. The Rangamati district shares international border with India (Tripura state to the north and Mizoram state to the east) and Myanmar (Chin State to the east) comprising of 1292 km2 is riverine and 4825 km2 is under forest vegetation [33].

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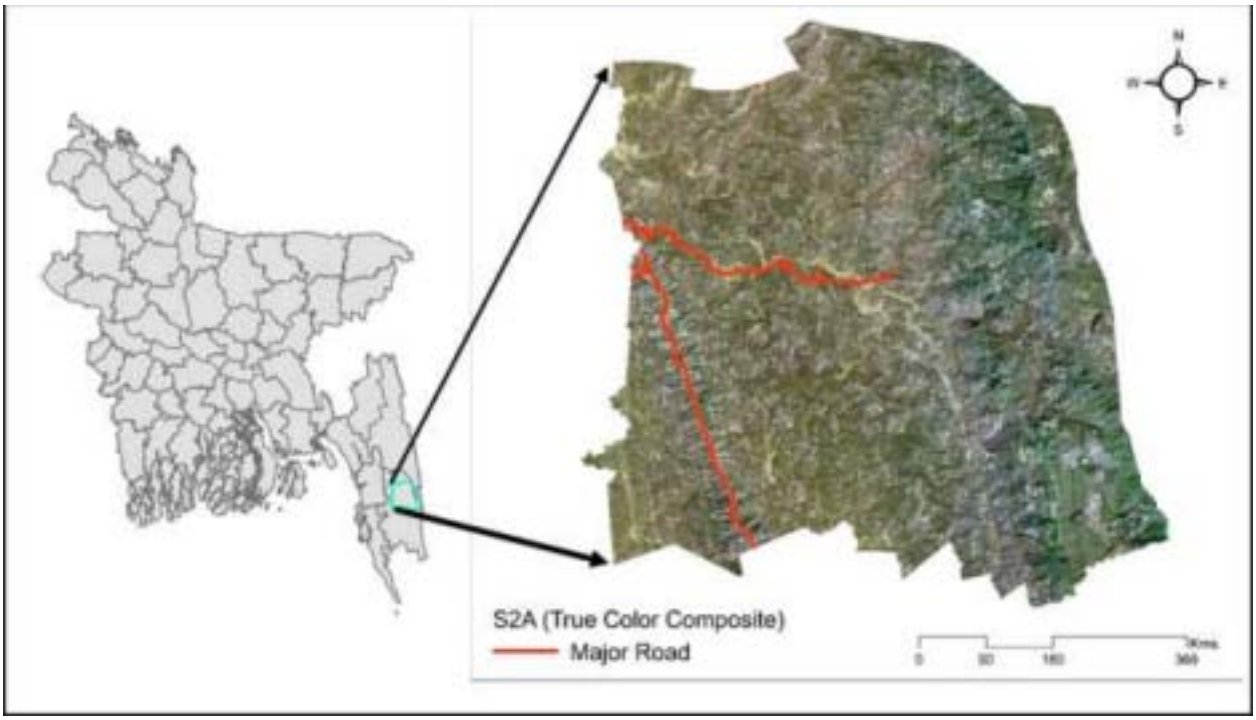

Figure 1: Study area showing in parts of Bandarban and Rangamati district

II. Methods and Materials

a) Satellite Data Used

European Space Agency (ESA) operated Sentinel 2A (S2A) multispectral remote sensing data acquired for the study. In the present study 10 m spatial resolution bands used (bands specifications are shown in table-1). At first cloud-free, orthorectified and radiometrically corrected S2A scenes acquired in 10 March 2018 was retrieved from Copernicus Sentinel Scientific Data Hub [34]. The S2 A data was processed using ESA SNAP 6.0 platform.

Table 1: Used Sentinel 2A data details

Used S2A Bands	Central Wavelength (μm)	Resolution (m)
Band 2 - Blue	0.490	10
Band 3 - Green	0.560	10
Band 4 - Red	0.665	10
Band 8 - NIR	0.842	10

The Advanced Land Observing Satellite-1 (ALOS), the Phased Array type L-band Synthetic Aperture Radar (PALSAR) ALOS-PALSAR 12.5 m spatial resolution open source and freely available DEM used in this research. The elevation of the study area varies 4 meters to 980 meters (Figure-2a). Figure-2a also denoted 10 primary samples and 3 selected samples from total of 13 samples on which the simulation model run. In figure-2b aspects details and in figure-2c the slope have shown where slope is categorized into four classes and found maximum slope in the hilly terrain in-between 31.9-77.5.

b) Model Input Data

i. *Digital Elevation Model*

The fundamental pre-requisite datasets for RAMMS model are digital elevation model (DEM) release area and mass along with friction properties and others associated geo-engineering parameters. Topographic settings is an initial input for simulation model of debris flow because the movement of flows will be determined, directed and dominated by elevation. Hence, high resolution precise DEM is required to define release area. The present study used ALOS-PALSAR 12.5m DEM. Two must needed inputs were given in debris flow modeling (i) Release/block release; and (ii) hydrograph. In this study, block release was favored due to its applicability.

Generally, RAMMS model usually follow unchannelized debris flow state particularly for superficial landslides and hill-slope debris flows. The designed model flow path was validated via satellite imagery. An important fact is the release area, for small unchannelized debris flows by a known initial height

which will be released as a block [35]. The release areas and approximate corresponding calculation domains had been identified and demarcated over the DEM (Figure-2a).

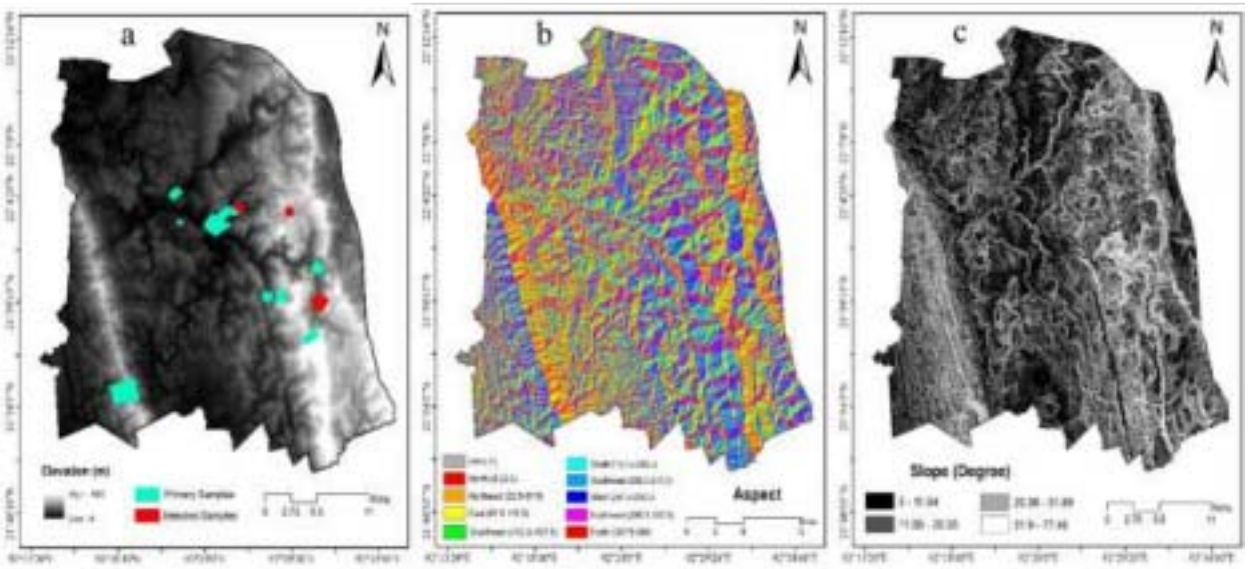

Figure 2: Elevation distribution throughout the study area (a); Aspect details (b); And slope variations

ii. *Others parameters and model calibration*

The rheological features and shear strength factors of slope is fundamental for RAMMS simulation model. The RAMMS physical model follows the Voellmy friction law [36] and (i) Dry-coulomb friction (μ); and (ii) Viscous-turbulent friction (ξ) are frictional resistance. The equation to calculate total frictional resistance (S) in Pa unit is as following

$$S = \mu\rho Hg\cos(\varphi) + (\rho gU2)/\xi$$

Assuming, g -gravitational acceleration, H -flow height, ρ -density of the debris, φ -slope angle, and U -initial flow velocity.

The collected samples were analyzed at the Indian Institute of Remote Sensing (IIRS), Dehradun at various capacity levels using shear testing electronic tools (Model No. AIM 104-2kN, Make Aimil Ltd, New Delhi). Samples were tested at 0.25, 0.50 and 1 kgf/cm2 regular load and subsequent shear strength factors at failure were determined.

RAMMS uses a single-phase model which is difficult for flow simulation with higher variety of debris flow materials. If the debris flow events are known the friction factors should vary to follow observed flow pathways so the simulation model ran multiple times to get desire results. Afterwards the best fit simulation outcomes were collected for further investigation [37]. A range of friction values used (e.g. dry friction 0.05-0.2) to fix optimal values and turbulent flow as 100-2000 m/s2 [37]. Others input factors e.g. release height, materials density, momentum and lambda (coefficient) were eventually retained constant. At the time *simulation* model flow found nearly 90% matched compare to real event the parameters frozen immediately. Among all typical outputs of RAMMS, momentum is relative. Momentum is measured in m^2/s unit, furthermore multiplied by density of debris and area under consideration to derive actual momentum in (kg*m/s).

III. Results and Discussions

a) Interpretation of simulation

Generally, RAMMS simulation provides four fundamental outputs are height, momentum, pressure and velocity. In addition, specific information of any point, line profile, run-out longitudinal profile are also possible to visualize in 2D and 3D format. The major concerns of ebris flow are height, velocity and momentum. The high expenses of clearing huge debris and the detachment of roads for the large quantity debris eventually interrupt the local inhabitant's daily life. Thereafter velocity and momentum plays vital role to signify remedial specifications (by type, magnitude and nature) to stop debris flow movement and damage reduction. The dynamic physical parameters of RAMMS simulations are narrated as following:

b) Mendrui Para

Debris flow-1 (Figure-3a) Mendrui Para, is beside Raikkhiyang Lake in the Eastern part of Bandarban. On the foot of the small hill local inhabitants occupied entire hazardous area by building human settlements. A small divergence into all branches observed from top to downwards. The simulated maximum flow height was 6.15m and maximum velocity 23.15m/s for flow-1. The debris flow-2 (Figure-3b) is slightly and flow-2 respectively. Comparatively debris flow-2 was little extensive than flow-1 with longer flow height (6.44m) and velocity (35.58m/s). The debris flow-

1 seems to be more dynamic as to velocity, pressure and thickness. The momentum was identified concentrated in the centre for flow-1 and surrounded for flow-2 proportionally following 59.59m^2/s and 113.96 m^2/s respectively. The distribution of pressure along the entrainment path was found 160.72kPa and 317.909kPa separately for flow-1 and flow 2.

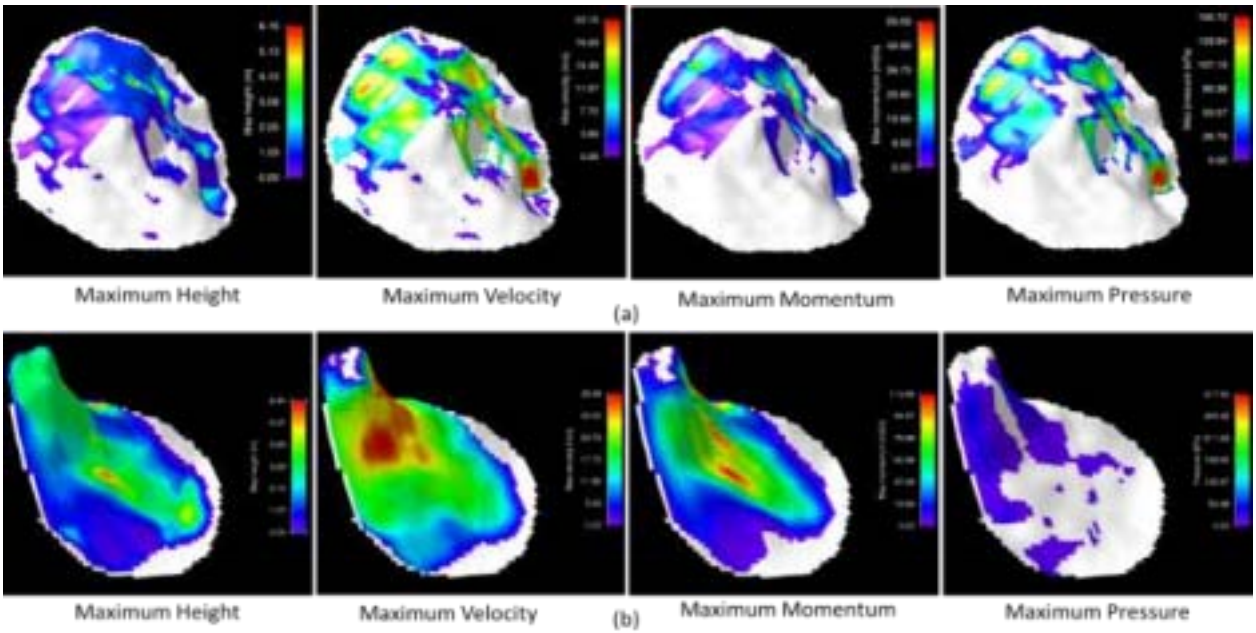

Figure 3: Simulation outputs of debris flow at Mendrui Para. (a) 3-D spatial variation of height, velocity, momentum and pressure along with run out path way of debris flow-1; (b) 3-D spatial variation of height, velocity, momentum and pressure along with run out path way of debris flow-2

c) *Prangsha Para*

Prangsha Para is basically settlement area and nearby western part of Rangamati district. A small channel goes to downstream of the hill foot. The simulated debris flow (Figure-4) model provides maximum flow height 1.11m and velocity 7.02m/s at the initial zone and gets surrounded afterwards. The height pressure recorded in the model 120.80kPa and the maximum momentum of 5.85m^2/s was observed at the primary zone.

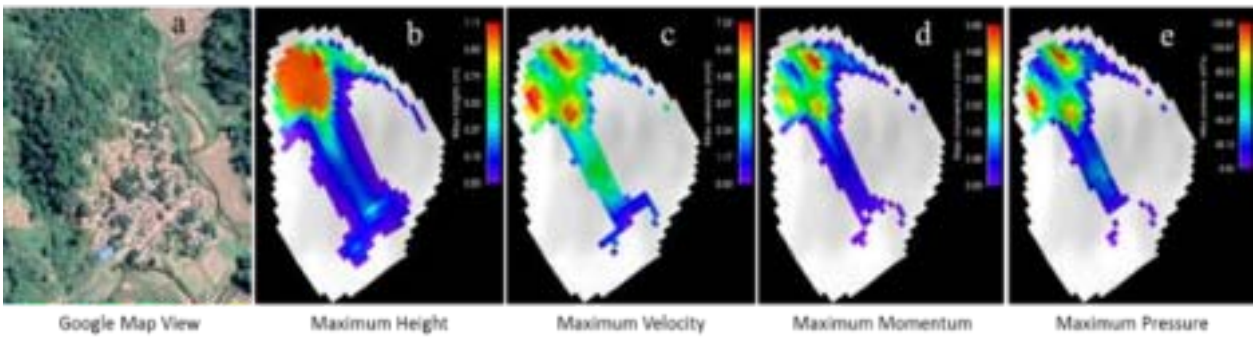

Figure 4: Google map view of present settlement status at Prangsha Para (a); 3-D spatial variation of maximum height, velocity, momentum and pressure along with run out path way of debris flow (b-e)

d) *Dadru Khyong*

Bottom of the selected hill human settlement found in hazardous situation at Dadru Khyong area. The debris flow simulated model (Figure-5) of the selected area was recorded 4.75m maximum height at the centroid. Model result show that maximum velocity of 22.78m/s at the centroid. Maximum momentum was found 54.09m^2/s.

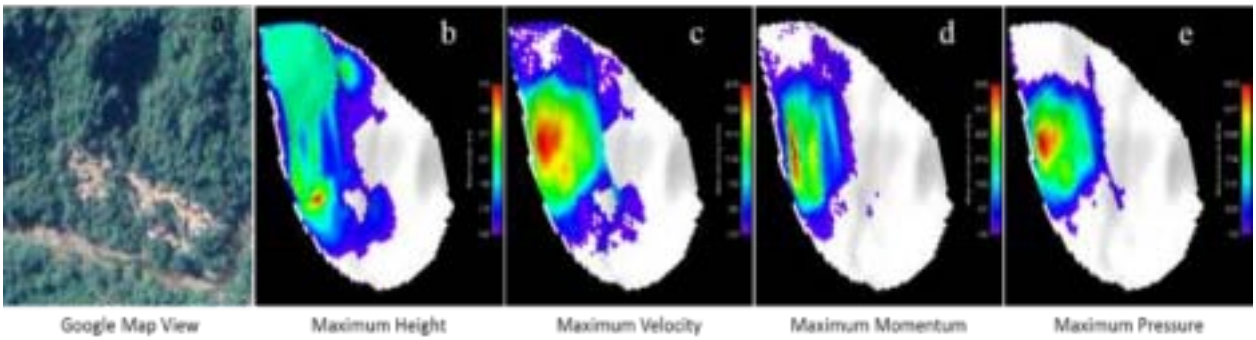

Figure 5: Google map view of present settlement status at Dadru Khyong area (a); 3-D spatial variation of maximum height, velocity, momentum and pressure along with run out path way of debris flow (b-e).

Overall, figure-6 describes the vertical profile of the three selected defies flow simulation area. The first one (Figure-6a) is showing the flow height and distance travel by the debris of *Mendrui Para* area which touches to 4.0m and suddenly slow down till the bottom. It has destructive impact on the local inhabitants due to the altitude variation tops to 350m. The second one (Figure-6b) is describing the maximum height relationship with distance covered by debris at *Prangsha Para* area which has a clear indication of rush flow over the settlement as the lowest altitude over 400m. And the third one (Figure-6c) is showing the maximum sheer stress varies and a sudden pick denotes extreme situation raising altitude till 200m.

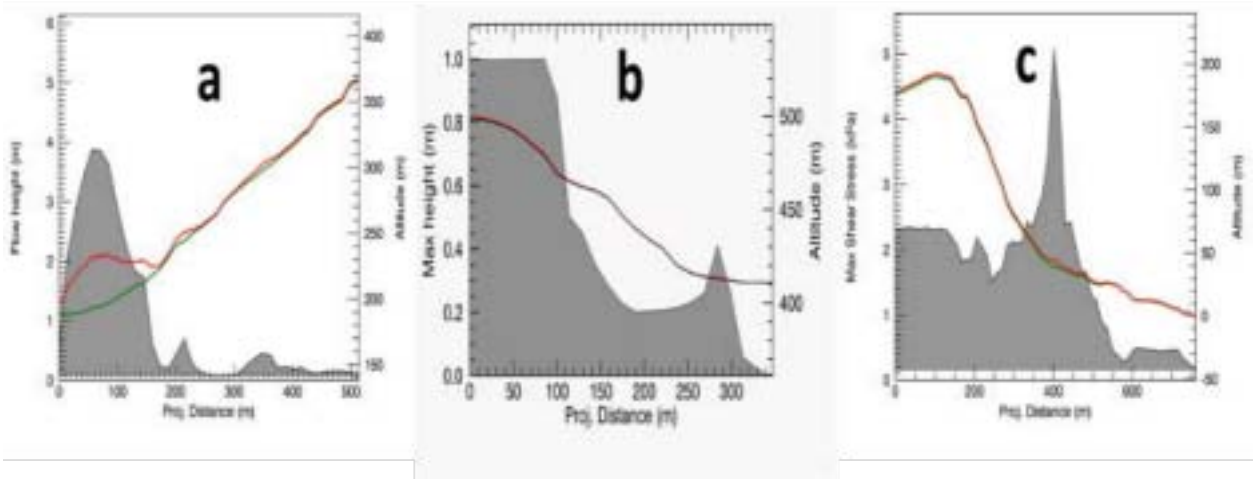

Figure 6: Vertical profile of the debris flow simulation. (a) *Mendrui Para* area flow height and covered distance relationship; (b) *Prangsha Para* area maximum height and covered distance relationship; (c) *Dadru Khyong* area Maximum sheer stress and covered distance relationship; And all the three have a common secondary axis altitude

IV. Conclusion

Overall the study concludes the following remarks:

- Dynamic physical flow parameters can be calculated using numerical simulation and flow modeling to aid mitigation, like height of check dams can be determined to digest initial thrust of the flow
- Collateral damage due to obstruction of rivers pathway and possible alteration resulting inundation can be assessed by knowing the velocity, height, pressure and momentum of modeled debris flow.
- Predictive modeling can be helpful in possible debris flows with little or no variation of geo mechanical properties at adjacent susceptible localities.

Conflicts of Interest: The authors declare no conflict of interest.

Authors' Contributions: M.M. proposed the topic. M.M. and S.L.C. commanded the research design, data processing, analysis, and wrote the manuscript.

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4. Use of computer is recommended: As you are doing research in the field of science frontier then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.
- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

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Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

INDEX

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