SEISMOLOGICAL AND GEOLOGICAL INVESTIGATION FOR EARTHQUAKE HAZARD IN THE GREATER ACCRA METROPOLITAN AREA

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BY

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DECLARATION

I, Maximillian-Robert Selorm Doku hereby declare that, with the exception of references to other people's works which have been duly acknowledged, this work is the result of my own research undertaken under the supervision of Dr. Paulina Ekua Amponsah and . Prof. Dickson Adomako and has not been presented for any other degree in this university or elsewhere, either in part or whole.

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Date Date

DEDICATION

This work is dedicated to my late mum, Esther Vugbagba.

ACKNOWLEDGEMENTS

I am very grateful to God Almighty for His guidance throughout this work.

Secondly, my appreciation goes in no small way to my supervisors Dr. Paulina Ekua Amponsah and Prof. Dickson Adomako. They have been very inspiring and tolerant of my shortcomings.

My sincere gratitude goes to my contemporaries and senior colleagues who have contributed in one way or the other to my work (School of Nuclear and Allied Sciences; Earth Sciences Department, University of Ghana and Ghana Atomic Energy Commission).

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Finally, my sincere gratitude goes out to all those who have not been mentioned, God bless you.

TABLE OF CONTENTS

CONTENTS PAGES

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

NADMO	National Disaster Management Organization
GAMA	Greater Accra Metropolitan Area
WWSSN	World Wide Standard Seismograph Network
CTBTO	Comprehensive Test Ban Treaty Organization
GAEC	Ghana Atomic Energy Commission
NDC	National Data Centre
ISC	International Seismological Centre
GPS	Global Positioning System
GIS	Geographical Information System
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
PF	Pan-African Front
WAC	West African Craton
CIGTM	Cote d'Ivoire – Ghana Transform Margin
CBF	Coastal boundary fault
GBC	Ghana Building Code

LIST OF SYMBOLS

µ	Micro
é	Latin small letter e with acute
√	Square root
α	Alpha
β	Beta
γ	Gamma
°	Degree
M_L	Local or Richter Magnitude
M_b	Body-Wave Magnitude
M_s	Surface-Wave Magnitude
M_D	Duration Magnitude
MM	Surface-Wave Magnitude (Measured from macroseismic events)
M_w	Moment Magnitude
M_o	Seismic Moment
M	Magnitude

ABSTARCT

A seismological and geological investigation for earthquake hazard in the Greater Accra Metropolitan Area was undertaken. The research was aimed at employing a mathematical model to estimate the seismic stress for the study area by generating a complete, unified and harmonized earthquake catalogue spanning 1615 to 2012. Seismic events were sourced from Leydecker, G. and P. Amponsah, (1986), Ambraseys and Adams, (1986), Amponsah (2008), Geological Survey Department, Accra, Ghana, Amponsah (2002), National Earthquake Information Service, United States Geological Survey, Denver, Colorado 80225, USA, the International Seismological Centre and the National Data Centre of the Ghana Atomic Energy Commission. Events occurring in the study area were used to create an Epicentral Intensity Map and a seismicity map of the study area after interpolation of missing seismic magnitudes.

The least square method and the maximum likelihood estimation method were employed to evaluate b-values of 0.6 and 0.9 respectively for the study area. A thematic map of epicentral intensity superimposed on the geology of the study area was also developed to help understand the relationship between the virtually fractured, jointed and sheared geology and the seismic events. The results obtained are indicative of the fact that the stress level of GAMA has a telling effect on its seismicity and also the events are prevalent at fractured, jointed and sheared zones.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Globally nobody is immune from disasters or disaster related losses. Therefore, this gives us enough reason to study them to know how best they can be handled in case they strike. Disasters are hazard situations that pose a level of threat to life, property or the environment. There are two major types of disasters. These are natural and man-made disasters. Hazards, on the other hand, are exposure or vulnerability to harm or risk (Microsoft Encarta Premium, 2009). Natural disasters include floods, fires, tropical cyclones, earthquakes, tsunamis and others which are environmentally related. However, hazards that strike in low vulnerability regions never become disasters.

Natural and man-made hazards usually come with deadly forces or retribution. Man-made hazards, however, are associated with transport, industry and health. Geological hazards include internal earth processes such as earthquakes, volcanic activities, emissions and related geophysical processes such as mass movements, landslides, rockslides, surface collapses and debris or mud flows are also hazardous.

In Ghana, disasters that can be identified include drought, earthquake, epidemics, storm, mass movement, extreme temperature, flood, insect infestation etc. The National Disaster Management Organization (NADMO) of Ghana in collaboration with other Agencies has been in the fore front trying to mitigate these hazard situations.

The Ghana Building Code (GBC) has clearly appreciated the relevance of mitigating measures to be taken to avert future disaster when flood and earthquakes occur in unplanned areas (GBC, 1988). The code, which was recently reviewed under the Africa Adaptation Program on Climate change recognized that buildings are the essential components of all human settlements and the focal point for all human endeavours for quality living. The review also observed that the GBC was not observable by development authorities, thus it lacks legal backing.

Building codes of Brazil and India have also been reviewed and it was realized that whereas these countries' codes specifically try to make provisions for earthquake, that of Ghana has paid more attention to floods, environmental degradation and fire and has not categorically tackled earthquake disaster. The review has however pointed out the hazard profile to include

- Perennial flooding
- Seismic activity
- Fire
- Air pollution
- Disease
- Environmental degradation and
- Coastal erosion

(CASA ASSSOCIATI, 2012)

One major disaster which has received some attention in Ghana is earthquake. Before the first documented earthquake in 1615, knowledge about earthquake was very scanty and not well understood.

In 1930, Charles F. Richter, a Californian Seismologist introduced the concept of earthquake magnitude, M_L (local magnitude), of focal depths 0-700 m of the Woods-Anderson torsion instrument already in use (Kossobokov, 2005). Since then various magnitude units have evolved, some of which are the M_b (body-wave magnitude), M_s (surface-wave magnitude) and M_w (the moment magnitude). Rather than relying on measured seismogram peaks, the M_w scale is tied to the seismic moment (M_o) of an earthquake. Additionally, in 1942, Guttenberg B. and Richter C. F. introduced the concept of relating earthquake data to the stress level in the ground, later called the Gutenberg – Richter relation. The idea of relating the frequency of earthquakes and the total number of earthquakes for specified periods threw more light on how earthquake monitoring can help mitigate disasters.

In Ghana, with special attention to the Greater Accra Metropolitan Area (GAMA), there is a tendency to conclude from a seismological and geological perspective that the stable continental region is really 'stable'. However, the history of earthquakes in Ghana and the sub region (dating back to 1615) proves otherwise (Amponsah, 2002). The major ones are the 1615 earthquake at Elmina and the 1636 earthquake with epicenter at Axim (5.7 M) which buried some miners alive after the collapse of the Portuguese mines. In 1862, Accra recorded 6.5 M earthquake killing three people (Junner, 1941). The most affected areas were the Usher and James forts and the Christianborg Castle which were rendered inhabitable. Additionally, the earthquake was registered as far as Togo. The

1939 earthquake (with epicenter located at Nyanyano) of the same magnitude as that of 1862 (intensity IX) and injuring 133 people has gone down in Ghana's history as the worse incident. However, the 6.5 M earthquake of intensity VIII on the modified mercalli scale killed 17 people (Amponsah *et al.*, 2012). The GAMA with population of 77000 experienced 17 deaths in the intensity VIII earthquake of 1939 (Amponsah, 2004). According to the 2010 population and housing census, GAMA currently has a population of about 3, 000, 000 (Ghana Statistical Service, 2010). Hence, there is the need to catalogue earthquake events to help understand what is happening in the area in order to plan for the future. Earthquakes have had huge impacts on various countries such as Haiti, Turkey and Ghana where there were loss of lives and properties. However, effective application of science and engineering principles to the development of the built environment has helped reduce the risk faced by earthquake-threatened cities of the developed world like the United States of America. Apparently, this cannot be said of developing countries like Ghana, where clear building codes have not been established and where simple regulations exist they are not followed (Allotey *et al.*, 2010).

Ghana recorded first earthquake in 1914, (Junner, 1941). Since then various significant attempts have been made by successive governments to help expand knowledge in seismic activities in the country and the sub-region. These national policy initiatives have led to the creation of national database of seismic activities and have gone a long way to support knowledge in geology of the coast of Ghana. With a continuum of risks associated with earthquakes, the installation of Milne's single-boom seismograph in the country was important. The instrument was used to locate hypocenters and to record earthquake magnitudes. In 1973, a seismograph observatory equipped with A World

Wide Standard Seismograph Network (WWSSN) system was established at Kukurantumi in the Eastern Region of Ghana.

The observatory operated continuously until October 1974 and then intermittently until continuous recording began again in 1977 (Amponsah, 2004). It had a nine station radio telemetric network with a central recording station at the head office of the Geological Survey Department in Accra until 2003 (analogue recording system) (Amponsah, 2004). Currently a digital recording system has been procured by the Government of Ghana. The facility is located in the Achimota forest, Accra, working under the authority of the Ghana Geological Survey Department (Opoku, 2012). The new network, with the central observatory in Accra would help enhance the monitoring of earthquakes and other forms of seismic activities. There are six seismic substations located at Morontuo, Kukurantumi, Shai Hills, Akosombo, Ho and Weija respectively. These stations are generating and transmitting data to the central observatory. Between 1636 and 2006, magnitudes ranging from 4.0 to 6.5 were recorded (Opoku, 2012). The seismic data being generated would help in a more efficient and effective land use planning, revision of building codes and policy formulation and the designating standards for official structures such as nuclear power plants, bridges, dams, overhead transportation systems and shopping centers. Events recorded can be used to locate earthquake prone areas through the generation of isoseismal maps and epicentral intensity maps. Peak ground acceleration can be calculated for and therefore hazard maps can be easily generated as well.

Observatories across the world are usually used to enhance the development of disaster mitigation strategies which usually help to reduce the effect of future earthquakes.

Therefore, planning of post-earthquake reconstruction programs to facilitate the development of well-defined insurance policies for protection against earthquakes is necessary. Also, enhancing public education on the need to sensitizing people of earthquake prone zones and their consequences cannot be overemphasized. Additionally, seismic data also plays significant roles in mapping active faults in a region. Currently measures are ripe for the installation of strong motion accelerometers on the Bui, Barekese and Owabi dams as well as quarry sensor equipment to be installed on mining and quarry sites to monitor man-made seismic hazard levels in the country (Wereko, 2012). To enhance the effective monitoring of earthquakes, the Comprehensive Nuclear Test Ban Treaty Organization (CTBTO) in conjunction with the Ghana Atomic Energy Commission (GAEC) has established the National Data Center (NDC) which has also been accessing seismic data from the International Data Centre since August, 2010. Interestingly, records obtained up to December, 2012 indicate earthquake events as high as magnitude 4.0 in and around the Greater Accra Metropolitan Area.

The relevance of earthquake data to petrochemical exploration, knowledge of local mechanisms of the subsurface and monitoring of nuclear tests cannot be overemphasized (Judson and Kauffman, 1990). Therefore data obtained by the Ghana Geological Survey Department and the Ghana National Petroleum Corporation played a meaningful role in discovering oil and gas in commercial quantities in 2007. The relevance of these data (Seismic events) to study the seismicity of GAMA by conducting a seismological and geological investigation for earthquake hazard cannot be overemphasized.

Earthquakes occur in many forms, but most intraplate earthquakes tend to be concentrated along pre-existing zones of weakness (including faults zones, suture zones, failed drifts and other tectonic boundaries) (Sykes, 1978). A careful study of the regional tectonic setting and evolution shows that south-east Ghana and its offshore are characterized by three areas with distinct tectonic zones. These are the Akuapem Fault Zone, Faults in the Coastal areas and Shelf, Fenyi –Yakoe and Adina Faults (Amponsah *et al.*, 2012). These fault zones cannot be isolated when it comes to exploring possible contributions to past seismic events.

The research is therefore aimed at quantifying the stress level of the GAMA by first cataloging all seismic data available up to 2012 and geologically investigating earthquake hazard by employing a mathematical model.

1.2 PROBLEM STATEMENT

Ghana has experienced significant damages resulting from earthquakes dating as far back as 1615. The 1939 earthquake has been the most significant in terms of damage to life and property. Therefore, many researchers have employed seismic data and geology to create hazard maps, delineating fault zones in the area of study. Accra, the capital city of Ghana has experienced some damaging earthquakes and tremors in the recent past (Amponsah, 2004).

However, the researchers failed to harmonize all the earthquake catalogue and models to estimate the stress level of the Greater Accra Metropolitan Area (GAMA) both seismologically and geologically and have never calculated the b-value from past earthquake catalogues available. This is necessary to serve as a guide for policy makers, engineers and fellow scientists in making critical decisions on settlements.

1.3 JUSTIFICATION

The 1986 study of earthquakes in West Africa showed Accra to be the most seismically active in the region (Ambraseys and Adams, 1986). Additionally, a study of world seismicity indicates the presence of a major preexisting tectonic boundary landward of large oceanic transform faults such as suture zones near Accra. This is indicative of a potential large shock in the future (Sykes, 1978). The Cameroon line and the Ngaourandéré fault zone are situated near the boundary between the Congo and the Pan-African belt deformation that extends as far as west of Accra (McConnell, 1969). The seismicity of Accra is one of the best examples of activity near the end of a fractured zone. Earthquakes in intraplate areas are not distributed at random but they occur mainly along faults and other zones of weakness associated with the last major orogeny of a region (Sykes, 1978).

Also, there is no detailed seismic hazard assessment map of the Greater Accra Metropolitan Area available to help with proper seismic micro-zonation of the city (Allotey *et al.*, 2010). The development of thematic mapping with the identification and characterization of seismically active zones constitute the framework for seismic hazard assessment. However, this is impossible without a comprehensive earthquake catalogue and an evaluation of the b-value which explains the stress level of the area.

Just like a seismicity map, an epicentral intensity map is also very important to evaluate the possible degree of damage should earthquakes of such magnitudes occur again.

Moreover, previous works have been silent on the use of the b-value in evaluating the stress level of the Greater Accra Metropolitan Area and coming up with relevant models to support this value. The importance of the b-value as an earthquake precursor cannot be overemphasized. Systematic study of b-values in New Zealand has shown that within the vicinity of forthcoming large earthquakes there is initially an increase in b-value and then a return to normal (Smith, 1981). Thus, fluctuating b-values of an area could serve as a clue for an imminent earthquake. Critical examples include the Caracas and San Fernando earthquakes which show the same phenomenon (Smith, 1981). The b-value can be used as earthquake precursor. Therefore this makes the research in the area very relevant.

1.4 OBJECTIVES

The research is aimed at employing a mathematical model to estimate the seismic stress for the Greater Accra Metropolitan Area.

Specific objectives include:

1. Creating a comprehensive and homogenized earthquake catalogue for Ghana from 1615 to 2012.
2. Evaluating the stress level of GAMA by calculating the b-value from the catalogue.
3. Generating a seismicity map.
4. Coming up with an epicentral intensity map.

CHAPTER TWO

LITERATURE REVIEW

2.1 PREVIOUS WORKS RELATED TO THE STUDY

A detailed report on the earthquakes in Ghana and a detailed analysis of the 1939 (6.5 M) earthquake has been given by Junner (1941). A geophysical investigation for the seismicity of the Weija area, Essel (1997) asserts that the area is seismically active. Using geological data to study earthquakes, Rajendran (2000) asserts that in many compression settings, faults tend to develop as splays or blind thrusts and not reach the surface. The rupture that reaches the surface tends to develop complex geometries. From the earthquake hazard point of view, it can be established that most earthquakes are temporally and/or spatially associated with weak zones. It is also observed that the Cameroon line and the Ngaourandere fault zone are situated near the boundary between the Congo and a belt of Pan-African deformation that extends as far as west of Accra (Sykes, 1978). Bacon and Quaah (1981) also attribute most of the epicenters occurring south of Weija, to be due to the existence of an old thrust zone which has been reactivated. Amponsah (2004) is of the view that most of the earthquakes in Ghana occur in the western part of Accra at the junction of the two major fault systems, thus, the Coastal boundary fault and Akwapim fault zone.

It has been observed that earthquakes in Ghana are concentrated in the area where the Akwapim fault intersects the coastal boundary fault. According to Amponsah (2002), seismic activity in Ghana is concentrated in the southeastern sector, at the junction between the two major active faults.

However, the seismic stratigraphic record of transpression and uplift on the Romanche transform margin offshore Ghana shows that the neotectonic activity around the Pan-African Structures may involve tectonic inversion (Attoh *et al*., 2003). Attoh et al. (2005) also tried to link the enhanced neotectonic activity near the south of the PF to the intersection of the PF and the Coastal boundary fault (CBF).

Additionally, Talwani (1998) also observes that although large earthquakes in continental interiors are much less frequent than those along plate boundaries, they have been responsible for a disproportionate amount of destruction. In furtherance of this he asserted that the nature of the seismicity in continental interiors is not well understood as that of its plate boundaries. Factors influencing earthquake generation in such areas include:

i. Rheological properties of the medium

ii. Nature of fault zones associated and

iii. Stress conditions

Earthquakes in Ghana are concentrated in the wider area where the Akwapim fault zone intersects the coastal boundary fault (Amponsah, 2004). Some of the epicenters have been located offshore and may be related to the activeness of the coastal boundary fault. The epicenters are related to the active parts of the faults, although because of many sources of inaccuracies it is not possible to assign them to individual faults or fault sections. Amponsah *et al.* (2009) modeled seismic ground motion of GAMA for land use planning and disaster mitigation by deterministic computation, using a hybrid method based on the modal summation and finite difference method. Peak Ground Accelerations

(PGAs) calculated ranged from 0.14 g to 0.57 g. It was observed that areas underlain by unconsolidated sediments experience the greatest shakings. Mavonga and Durrheim (2009) compiled all available catalogues in the region 14 º S to 6 º N and 10 º E to 32 º E from 1910 to 2008 for the Democratic Republic of Congo and surrounding areas. They calculated the b-values for three key active areas namely, Upemba-Moero Rift, Congo Basin and Western Rift and obtained 0.813, 1.020 and 0.773 respectively.

The above works have laid credence to the fact that earthquake hazard in some parts of the stable continental region are real. However, none has tried calculating the b-value for the Greater Accra Metropolitan Area. The research is therefore aimed at calculating the b-value to help examine its characteristic impact on GAMA and find out if it has any bearing on earthquake hazard.

2.2 THE b-VALUE AND EARTHQUAKE OCCURRENCE

Earthquakes are not uniformly distributed in time, space and magnitude. The distribution of earthquakes with respect to magnitudes exhibits scale invariability and obeys a power law usually referred to as the magnitude-frequency relation.

The relation however, exhibits some deviation from linearity which is due to the fact that magnitude scales saturate and also there are problems associated with the way magnitudes are measured. Sometimes the catalogues available to work with are too short and rarer large magnitudes are missing (Kulhanek, 2005). Whereas Kagan (1999) believes that b-values rarely change, others like Felzer (2006) with a lot of credible publications believe there are significant spatial and temporal variations in b-values.

Instrumental data shows that large earthquakes (M ≥ 7.2) are less frequent than expected from smaller ones. Also, with small-time sampling, b-value is reasonably well estimated from smaller earthquakes, but not for large ones. High and low stress can cause earthquake series with low and and high b-values respectively. This is an observation that can be used to study stress levels and structural anomalies in the crust and/or upper mantle (subduction) (Kulhanek, 2005). According to Wiemer *et al* (1998), earthquake predictions and identification of volumes of active magma is possible when this observation is employed.

2.3 GEOLOGIC STRUCTURES AND SEISMICITY

Generally, GAMA is low-lying. With reference to Nyanyano, the epicenter of the 1939 earthquake, prominent ranges of hills running from north-east direction from the coast and rising to more than 600 feet above sea level occur. In fact, the area is slightly undulating (Junner, 1941).

The effects of earthquakes on buildings and other structures vary greatly depending on the underlying rocks. The tectonogeological units of GAMA are interspersed with the five distinct tectonogeological units of Ghana. These include

- The paleoproterozoic complex of the West African Craton (WAC)
- The Voltaian basin of the WAC
- The Akwapim Togo belt
- The Pan-African province of neoproterozoic metamorphic age
- Several small sedimentary basins of Post-African age

The tectonic setup of GAMA and its offshore area is characterized by three areas with distinct tectonic elements namely, the Akwapim fault zone, faults in the coastal area and near coast shelf with the coastal boundary fault as main feature, and the Romanche fracture zone (Amponsah *et al.*, 2012).

Attoh *et al*. (2005) were also convinced that neotectonic activity along the Pan-African structures may involve tectonic inversion as well as tectonic reactivation along the seismic Pan-African fracture zone (which may have occurred in the Paleozoic era and again more recently along the Pan-African sutures)

To understand the phenomena of intraplate seismicity of the study area, the connection between the Pan-African Structures and seismic activity along the coast of Ghana must be well examined. This is evident in the several events recorded on and off-shore GAMA. The seismic stratigraphic record of the Ghana margin also strongly indicates that sub-aerial erosion related to uplift was later than or accompanied the folding, rather than earlier and as such transpressional deformation likely contributed to the uplift along the Cote d'Ivoire – Ghana Transform Margin (CIGTM) (Attoh *et al*. 2003)

In certain areas in Accra such as Weija, where the Akwapimian rocks have been observed to contain bands of soft Phyllite and are fractured and faulted, the area has recorded a lot of seismic activity.

2.4 SEISMICITY OF GAMA AS COMPARED TO OTHER INTRAPLATE REGIONS

Comparing the epicenters of earthquakes for the period 1900 to 1973, it may be concluded that the seismicity of the West Coast of Africa is low (Singh *et al*., 2009).

Additionally, like other intraplate regions, GAMA, some parts of the Scandinavia and Greenland have recorded earthquakes of magnitude 2.5 and above (Gregersen, 2006). The East African Rift System has also recorded earthquakes with average focal depth of 20 km. However, the Eastern Rift seismic activity seems to be more concentrated in swarms of certain areas. In Ghana, the most damaging earthquake was the 1939 earthquake, which recorded a focal depth of 18 km at Nyanyano, near Accra-Ghana. The disaster took seventeen (17) lives and hundreds were injured (Amponsah *et al.*, 2012). Table 2.1 gives a brief breakdown of Ghana's seismicity indicating concentration of activities in GAMA.

Table 2.1: Ghana's Seismicity

Year	Magnitude	Remarks
1615	-	Felt in Elmina
1636	5.7	Felt in Axim. Buildings as well as underground workings of Portuguese mines collapsed.
1862	6.5	Every building in Accra was razed to the ground. The Osu Castle and Forts in Accra were rendered uninhabitable. The shocks were felt in Togo where water in the Mono river fell much below its normal level.
1906	5.0	Many buildings in Accra particularly castles and forts were cracked. The earthquake was felt in other areas as far as Togo.
1939	6.5	Intensity was greatest in areas between Accra, Weija, Gomoa Fete and Nyanyano. The computed peak ground acceleration ranges from 0.14g to 0.57g corresponding to VII to IX on the Modified Mercalli Scale. In Accra 16 people were killed with 133 injuries.
1964	4.5	Felt mainly in Akosombo.
1969	4.7	Felt mainly in Accra.
1997	3.8	Felt mainly in Accra
2003	4.8	Felt in some parts of Accra
2011	4.0	Near Coast of Ghana/Togo
2012	4.2	Near the Coast of Accra

CHAPTER THREE

STUDY AREA

3.1 LOCATION

Accra, the capital city of Ghana is located at 5 ° 30 ' and 0 ° 10 ' W and has a population of about two million three hundred thousand people (Ghana Statistical Service, 2012). The Greater Accra Metropolitan Area (GAMA) comprises about four administrative districts with a total area of about 1,000 square kilometers, which includes the Accra Metropolis, the Tema Metropolis, the Ashaiman Municipal, the Adenta Municipal, and the Ga district assemblies (recently divided into Ga East and Ga West). GAMA is the most industrialized area in Ghana and is the most dominant center of commerce, finance, manufacturing, education and trade (Allotey *et al.*, 2010).

The map of the study area is shown in fig. 3.1

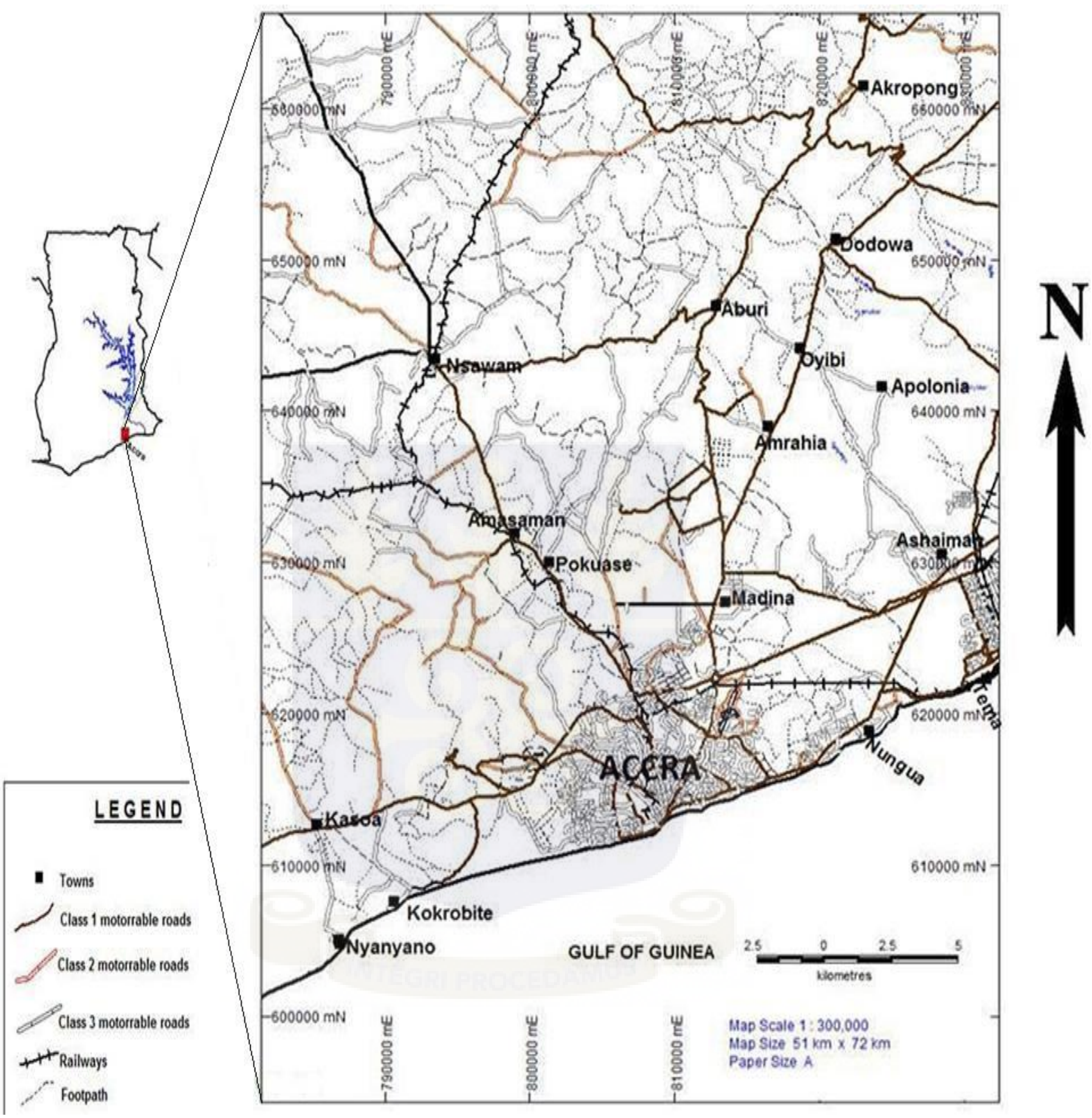

Fig. 3.1: Topographical map of study area (Modified from the Topographic map of Ghana, 1972)

3.2 GEOLOGY OF THE STUDY AREA

The geology of the Greater Accra Metropolitan Area, (GAMA) comprises six geological formations (Fig. 3.1). These are:

- Unconsolidated and poorly consolidated sediments and soils of Quarternary and Tertiary age; covering areas such as Korlebu, Abossey Okai, Mataheko, Adabraka, Achimota, Dansoman and Odorkor. This formation is dominated by Red Continental Deposits; Marine Fluvial or Lacustrine Sediments; Consolidated Beach Sediments and Unconsolidated or Slightly Consolidated Cobble Colluviums (Muff and Efa, 2006). The area is mostly interspersed with thickly bedded sandstones and mica schists.
- The Accraian Group of Devonian age comprising the Upper Sandstone-Shale Formation, Middle Shale Formation and Lower Sandstone Formation covers areas such as North Kaneshie, Osu, Kanda, Kpehe, Alajo and the city center Accra (the capital). This area is mostly underlain by thickly bedded sandstones interbedded with shale.
- The Voltaian Supergroup of Lower Paleozoic age is mainly made of Quartzose and impure sandstones. The system covers areas such as Anamorley and parts of Olobu and Ablekuma.
- The Togo Structural Units are made up of quartz veins, phyllite and phyllonite, quartz schist (sericitic quartz schist) and quartzites. The Structural Units cover areas such as Weija, Mandela, Nyanyano, Anyaa, Oblogo, Sowutuom, Burma Camp, Dome, Ofankor, Kwabenya and parts of the Ghana Atomic Energy Commission. The Togo Structural Units are of Upper Precambrian age. Key

among these rocks includes granitoid and biotite gneiss, quartzite minor mica schist and thickly bedded sandstones.

- The Dahomeyan Supergroup comprises the basement rocks of Middle-Late Precambrian age. This comprises quartz schist, Orthogneiss, Metamicrogabbro and Amphibolites and Scistose Marbles. Madina, parts of Atomic Energy Commission and Mpehuasem are located on this formation. The Supergroup is specifically underlain by garnet amphibolite gneiss covering Amrahia, Ashaiman, Tema and Nungua as well.
- Also, forming part of the Greater Accra Metropolitan Area geology is the Middle Precambrian aged Granitic intrusions made of deeply weathered Granitoid-Pegmatite Complex and covering Adzen Kotoku, Amasaman and Oduman.

The geology of GAMA is generally interspersed with lineaments, concealed, observed and thrust faults and shear zones as pictured in the geological map (Fig 3.2). The weak coastal boundary faults with mild stones along the coast characterized by shear zones, joints and fractures re-emphasize the non-uniformity in geology in GAMA. Additionally, they are older fault zones reactivated by continental fragmentation (Singh *et al.*, 2009; Rajendran, 2000). Key faults in the study area include

i. Longitudinal faults

    (a) Eastern boundary faults

    (b) Western boundary faults

ii. Faults parallel and sub-parallel to the coast

iii. Northerly striking faults and

iv. Transverse faults

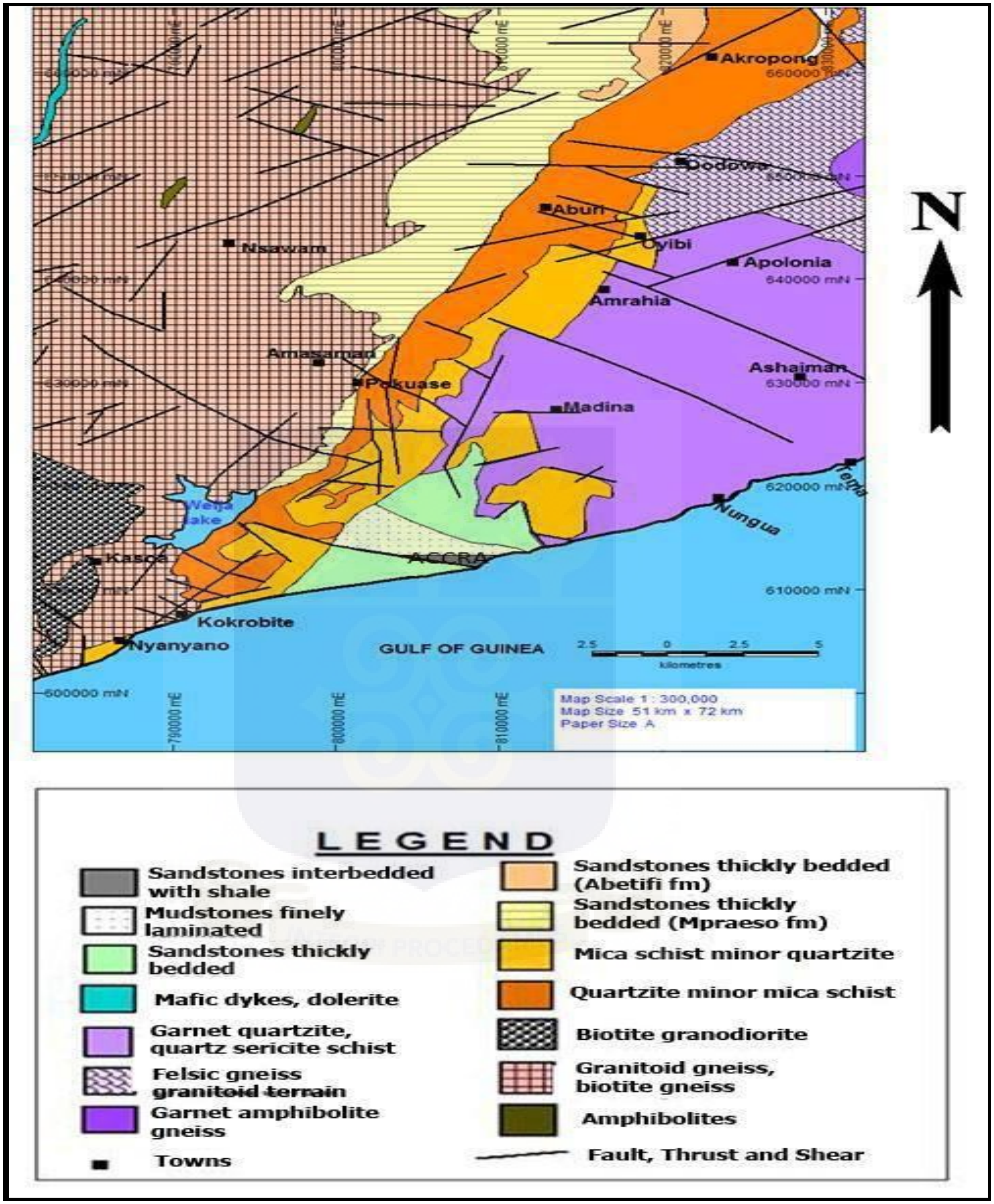

Fig. 3.2: Geology of the Study Area (Extracted from the Geological Map of Ghana, 2009)

3.3 SOILS

The soils in the study area are categorized into four main groups, namely: drift materials, alluvial and marine motted clays, residual clays and gravels and lateritic sandy clay soils (Muff and Efa, 2006; Kortatsi *et al*., 2008).

The drift materials result from deposits by wind-blown erosion whilst the alluvial and marine motted clays of comparatively recent origin are derived from underlying shales ((Muff and Efa, 2006; Kortatsi *et al*., 2008). Weathered quartzites, gneiss and schist rocks produce the residual clays and gravels whilst the laterite sandy clay comes from the Accraian sandstone bedrock formations. There are pockets of alluvial "black cotton" soils found in many low lying poorly drained areas. Soils in GAMA have heavy organic content and expand and contract readily causing major problems with foundations and footings (Muff and Efa, 2006; Kortatsi *et al*., 2008).

Concrete foundations are prone to attacks from highly acidic laterite soils present in some areas, thereby causing honeycombing. Large areas of coalluvial laterite gravels and sands are near the foothills.

Three main erosion types are prevalent in the metropolis. These are;

i. Sheet erosion: this occurs mainly on the steeper foothill slopes where the natural vegetation cover has been removed due to the adoption of bad farming practices.

ii. Gully erosion: this occurs mainly along major drainage channels

iii. Wind erosion: this is confined to coastal and dune areas. Coastal erosion is a very serious problem in GAMA (it is estimated that part of the coastline is retreating at a rate of 0.5metres per year) (Muff and Efa, 2006; Kortatsi *et al*., 2008).

3.4 CLIMATE AND VEGETATION

3.4.1 Climate

Accra lies in the Coastal Savannah Zone. There are two main rainy seasons with an annual rainfall of about 730 mm (primarily during the two rainy seasons). The following bulletins highlight the key aspects of GAMA's climate. The first rainy season starts from May to Mid-July and the second rainy season starts from Mid-August to October. Rain falls in intensive short storms and where drainage is poor, local flooding occurs. Temperature variations during the year are very little with mean monthly temperatures between 24.7 °C in August and 28 °C in March and an annual average temperature of 26.8 °C. The climatic condition of the Greater Accra Metropolitan Area is such that daylight hours are uniform throughout the year since the study area is closer to the equator. Relative humidity is generally high (i.e., 65% at mid-afternoon to 95% at night). The wind direction is predominantly WSW to WNW (wind speed is usually 8 to 16 kmh^{-1}). The maximum wind speed in GAMA is usually 107.4 kmh^{-1}, thus about 58 knots. At the foothill slopes of the Akwapim hills the wind velocity increases and gives rise to slightly cooler temperatures (Muff and Efa, 2006; Kortatsi *et al*., 2008).

3.4.2 Vegetation

The study area is characterized by terrestrial and aquatic vegetations.

The terrestrial vegetation is altered in recent past century due to climatic and other factors. GAMA was earlier covered by dense forest of which only few remnant trees are visible today. The vegetative structures are similar to those of the Southern Shale, Sudan and Guinea Savannas all of which lie north of the Accra plains. These have been imposed by climatic change and gradient of the plains and cultivation of the land. There are three broad terrestrial vegetative zones namely

i. Shrub land: This occurs in the western outskirts and in the north towards Aburi hills. Dense clusters of small trees and shrubs which grow to average height of about 5 metres are present.

ii. Grass land: They are a mixture of species found in the undergrowth of forests. The grasses are short and rarely grow beyond 1 metre.

iii. The Coastal zone is further made of two vegetations. They include the wetlands and the dunes.

A number of introduced trees and shrubs thrive in GAMA. In the Accra area, trees like Neems, Mangoes, Cassias and Avocados and Palms. Shrubs like Bouganvillia also exist. The coast is mainly dominated by mangroves and Coconut plantations.

Aquatic vegetation in GAMA comprises mangroves and salt marsh grasses. These are common in the intertidal zone whilst sea grasses and attached algae can be seen around the rocky areas and wave cut platforms. The aquatic vegetation is increased due to erosion (exposing bedrock especially to the east of Tema). The ocean floor sea grasses are confined to a few sheltered areas of the coastline and the lagoons (Muff and Efa, 2006; Kortatsi *et al*., 2008).

3.5 DELIMITATION OF STUDY AREA

To clearly understand the seismicity of GAMA, the area needs delimitation. Immediate environments around GAMA must be compared to other areas of similar geology such as Togo, Burkina Faso and Cote d'Ivoire. It is well known that earthquakes have no geographical boundary. The inclusion of these places would also help obtain enough data for the stress estimation of the study area. Mavonga and Durrheim in the Probabilistic Seismic Hazard Assessment for the Democratic Republic of Congo and surrounding areas calculated the b-values by including data from the sub-region (Mavonga and Durrheim, 2009). In analyzing seismic activities in Ghana, seismic data from the immediate neighbours of Ghana were also considered (Amponsah, 2004).

CHAPTER FOUR

METHODOLOGY

4.1 DESK STUDY

The necessary information relevant to the study was gathered from the Accra Metropolitan Assembly, Ghana Geological Survey Department and the National Data Centre of the Ghana Atomic Energy Commission. Additionally, other research works conducted in the area were also gathered to have a fair knowledge about seismic activities in the study area. Some of these communities such as Accra Central, Weija, Kwabenya and Nyanyano were visited to gain an insight into current structural readiness in case any of the past events is repeated. In Accra Central, short buildings are being replaced with high rising ones. Weija on the other hand has become a bit developed with modern structures but most unplanned settlements surround the lake. This area is noted for high seismic activity from past seismicity evaluations. Kwabenya and Nyanyano lands are being given out for development but no significant attempt has been made to build earthquake resistant structures even though modern structures in these places are stronger than earlier ones.

4.2 EARTHQUAKE CATALOGUE

The most important and essential parameter for hazard studies is the earthquake catalogue (Parvez *et al.*, 2001). Earthquake data from 1615 to 2012 was used for this seismological and geological investigation. The flow chart below (Fig. 4.1) demonstrates the processes involved in generating the catalogue

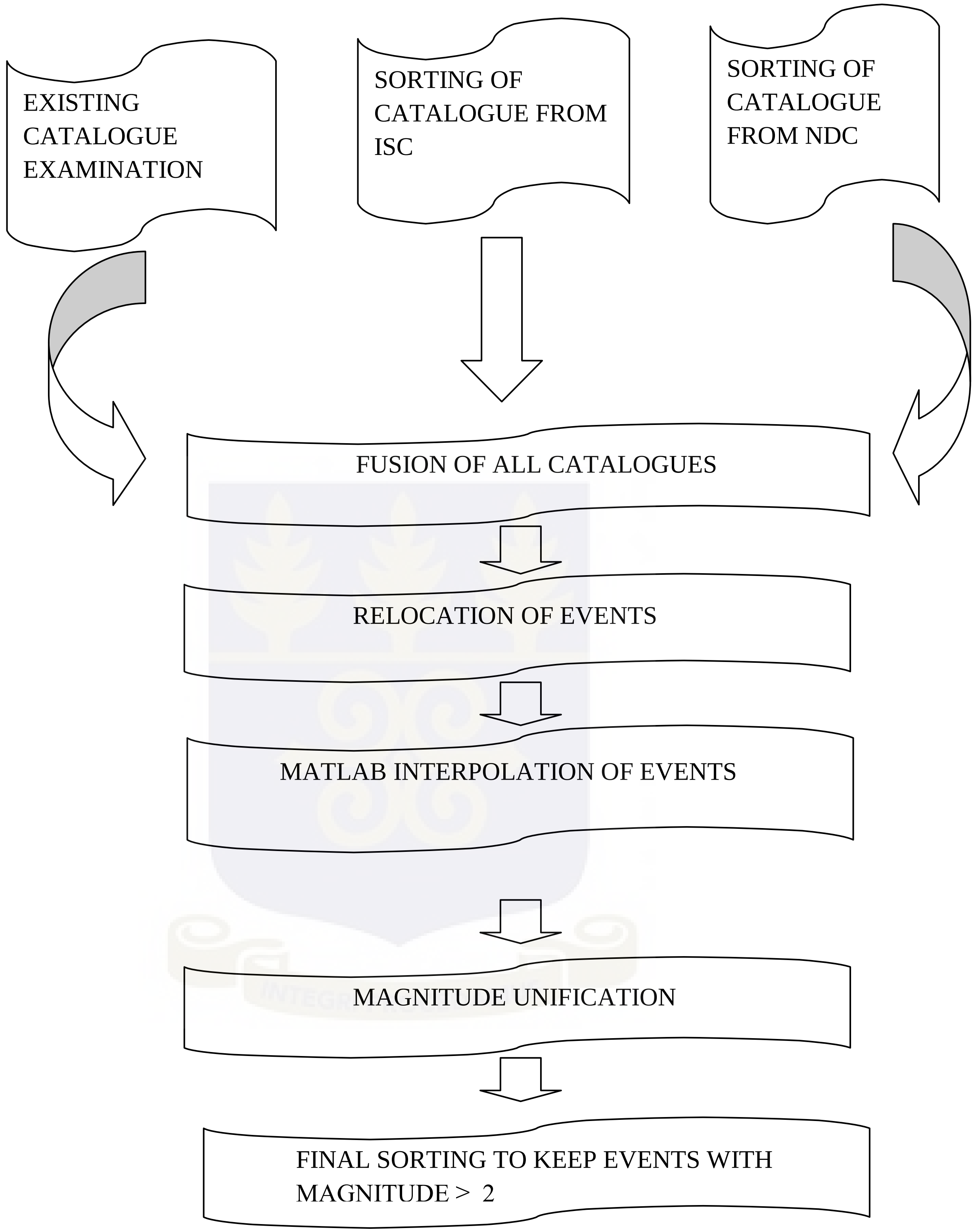

Fig. 4.1: Flow Chart for Developing GAMA Seismicity Catalogue

4.2.1 Data Collection

Seismic events spanning 1615 to May 2003 was obtained from Amponsah *et al.* (2012). Events from June 2003 to December 2009 were obtained from the International Seismological Centre (ISC, 2012) using rectangular grid. The rest of the data was obtained from the National Data Centre at the Ghana Atomic Energy Commission.

4.2.2 Interpolation of Earthquake Magnitudes

The Matlab Programming Software was used to generate the magnitudes of events without magnitudes. In that, the input data include years and their corresponding magnitudes. Some of these include 1636, 1862 and 2012 with their corresponding average magnitude for events being 5.8 M, 5.7 M and 6.2 M. This was done in the editor window. After entering this data and running it, the output data was then displayed in the command window. For years with multiple records, an average of the event magnitude was calculated. In order to validate the program, years of known magnitude of events were commanded. On running the program the results affirmed the already known magnitudes. The results are accordingly expounded in Chapter five.

4.2.3 Relocation of Events

Some events from Amponsah *et al*. (2012) were relocated to reflect the present day areas that experienced the earthquake. This would help in better interpretation of the earthquake hazard in the Greater Accra Metropolitan Area. In some cases the events were not exactly at city centers and the relocation of the events would help in estimating the best intensity of the seismic events if they should occur in present day. In some cases where the relocation is unable to clearly identify the epicenter from the Google Maps Application Software, the Global Positioning System (GPS) was used to identify the area concerned. This was mainly done in areas such as Weija, Nyanyano and the City of Accra which have recorded significant earthquakes and tremors in the recent past.

4.2.4 Magnitude Unification

The catalogue produced contained various magnitude units. These include the Local Magnitude, M_L, the Body-wave Magnitude, M_b, the Duration Magnitude, M_D and the Surface-Wave Magnitude for macroseismal data, MM. The different magnitude scales used in describing the size of the earthquakes in the catalogue calls for unification and harmonization. All the units must be converted to one single unit where possible, since the earthquake magnitude scale is one of the most fundamental earthquake source parameters used for catalogues. Drawing a unified relationship between these scales would help in a better hazard and risk assessment by improving on uniformity and continuity of the data. The moment magnitude was used because it is a direct indicator of the seismic moment of an event and also this magnitude relates to some physical parameters of the fault such as the amount of slip (Hanks and Kanamori, 1979; Mavonga and Durrheim, 2009).

The following relations were used to convert the various magnitude units to the Moment Magnitude, M_w. However, for small events, magnitudes M_L and M_b were considered to give reliable measure of events (Hanks and Kanamori, 1979; Mavonga and Durrheim, 2009). Events spanning 1615 to 2003 were recorded in M_D, MM and M_L. M_D was converted to M_L according to Brumbaugh (1987) as:

$$M_L = 0.936\ M_D - 0.16 \pm 22 \quad (4.1)$$

where;

M_L is the Local magnitude and M_D is the Duration magnitude

This linear regression relation (equation 4.1) has been used for evaluating magnitudes in local and regional seismic networks. One advantage of the duration magnitude however, is that it allows rapid estimates for large number of local events (Brumbaugh, 1987).

The rest of the relations relied on during the harmonization include the following; according to Hanks and Kanamori (1979) and Mavonga and Durrheim, (2009):

$$M_s = 2.08M_b - 5.65 \quad (4.2)$$

$$M_b = 0.481M_s + 2.716 \quad (4.3)$$

$$M_b = 1.7 + 0.8M_L - 0.01M_L^{2} \quad (4.4)$$

$$Log_{10}{}^{Mo} = 1.5Ms + 16.1 \pm 0.1 \qquad 5 \leq Ms \leq 7.5 \quad (4.5)$$

$$Log_{10}{}^{Mo} = 1.5M_L + 16.0 \qquad 3 \leq M_L \leq 7 \quad (4.6)$$

$$M_s = 1.45M_L - 3.2 \quad (4.7)$$

$$M_{b,\ ISC} = 0.46M_s + 2.74 \quad (4.8)$$

$M_w = 2/3\ Log_{10}{}^{Mo}\ 10.7$……………………………………………………...….4.9

where;

M_s is the Seismic-wave magnitude

M_b is the Body-wave magnitude

M_o is the Seismic moment

M_L is the Local magnitude

$M_{b,\ ISC}$ is the Body-wave magnitude according to the ISC standards

M_w is the moment magnitude

The National Data Centre records captured in M_L and M_b were maintained where the conversion leads to a reduction in magnitude. This would help consider extreme scenarios of earthquakes occurring instead of maintaining lesser earthquake magnitudes that can only be used to evaluate less effect.

4.3 SEISMICITY AND EPICENTRAL INTENSITY MAPS

A seismicity map was generated to evaluate the frequency, magnitude and distribution of earthquakes up to 2012. The epicentral intensity map was generated according to Herak (2012) equation defined as:

$I = M + 2$ ………..……… ……………………………………………………….4.10

where;

I is the epicentral intensity whilst M is the magnitude, Equation 4.10 was used to convert the magnitudes to epicentral intensities. The coordinates, thus latitude and longitudes were also converted to metres using Franson CoordTrans software (version 2.3). The conversion helps to arrive at a more accurate location of the epicenters as compared to the latitude-longitude approach. The epicentral intensity was plotted using the Geographical Information System, GIS. The plot also indicates the distribution of earthquakes in space in the Greater Accra Metropolitan Area as shown in Figure 5.1.

4.4 EVALUATION OF b-VALUE

Two approaches were adopted to evaluate the b-value. These are the;

i. Linear least square fit

ii. Maximum likelihood estimation

The linear least square fit is the Guttenberg-Richter approach which uses the Guttenberg-Richter magnitude frequency relationship (Guttenberg and Richter, 1942). This empirical relation expresses the relationship between magnitude and the total number of earthquakes in a given area and the time period of at least that magnitude. The relation is given as:

$$\mathrm{Log}_{10} N (\geq M) = a - bM \qquad 4.11$$

where,

N is no. of events with magnitude $\geq$ M,

M is the magnitude of the events,

a and b are constants, thus a describes the seismic activity (log number of events with M=0). It is determined by the event rate and for certain region depends upon the volume and time window considered. b, which is typically close to 1, is a tectonic parameter describing the relative abundance of large to smaller shocks. It seems to represent properties of the seismic medium in some respect, like stress and/or material conditions in the focal region (Kulhanek, 2005).

Comparing equation 4.11 to the equation of a straight line (equation 4.12),

$$y=c+mx \qquad \text{4.12}$$

where;

y represents plots on the vertical coordinate

x represents plots on the horizontal coordinate

c represents the y-intercept

m represents the gradient of the plot of y against x

Then equation 4.11 can be re-written as:

$$y = \text{Log}_{10}\, N\,(\geq M) \qquad \text{4.13}$$

$$x = M \qquad \text{4.14}$$

and the gradient

$$m = -b \qquad \text{4.15}$$

Log_{10} N (≥ M) was evaluated from the catalogue with the corresponding cumulative magnitude M as shown in Table 5.1,

The result obtained from the plot of equation 4.13 against equation 4.14 was used to evaluate the b-value (the slope of the graph) according to the equations 4.11, 4.12, 4.13, 4.14 and 4.15. One interesting feature of this method is that all the Log_{10} N (≥M) values evaluated take part in the calculation (Chen *et al.*, 2003).

Marzorcchi and Sandri (2003), Lombardi (2003) and Felzer (2006) approaches were adopted to estimate the b-value by the maximum likelihood process using the equation 4.16 given below

$$b=1/[\ln 10\,(m_{av}-m_c)] \qquad 4.16$$

where;

b represents the b-value

m_{av} represents the average magnitude from the catalogue and

m_c represents the threshold or cut off magnitude (usually carefully selected from the sharp curve exhibited by chart). The completeness of the earthquake catalogue, i.e. the estimation of the so-called threshold magnitude m_c is critical. In general, m_c magnitude of data set is obtained from the Guttenberg-Richter relation plot (plotting Log_{10} N (≥ M) against the magnitudes, M). m_c is the level at which the data falls below the line of best fit (Lin *et al*., 2008; Wang and Shieh, 2004)

Marzorcchi and Sandri (2003) reviewed and gave new insights on the estimation of b-value and its corresponding uncertainty. The new insights given involved the introduction of the maximum likelihood estimation method and further went on to calculate the uncertainties associated. Lombardi (2003), on the other hand, used the maximum likelihood estimator to calculate the b-value of mainshocks and compared the results to the Guttenberg-Richter method of least square fit. Felzer (2006), in calculating Californian seismicity rates from the earthquake catalogue for time-independent hazard analysis adopted the maximum likelihood estimation method.

According to Aki (1965), the uncertainty associated with b-value calculation is given by

$$\sigma_b = b/\sqrt{N} \quad \text{..........4.17}$$

where σ_b represents the uncertainty, b represents the b-value and N represents the number of earthquakes under consideration

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 RESULTS

5.1.1 EARTHQUAKE CATALOGUE

An earthquake catalogue has been created, and this is an improvement on the one generated by Amponsah *et al.* (2012). In all, 554 events from 1615 to 2012 from Ghana and its neigbouring countries were used in this study. The interpolated earthquake magnitudes were computed using Matlab software which generated the earthquake magnitudes between 2.9M_w and 6.6M_w. The catalogue is shown in Table 5.1

Table 5.1: Earthquake Catalogue of Ghana and its Immediate Neighbours (1615 to 2012)

Yr	**M**	**D**	**H**	**Min**	**Sec**	**Lat**	**Lon**	**Dp**	**M_L**	**Mb**	**MM**	**Mw**	**Io**	**RS**	**Az**	**Ref**	**Location**
1615						5.1	-1.3						8			AMB	Elmina,Ghana
1636	12	18	14			5.1	-2.2					5.8	9			AMB	Axim, Fort Duma, Awoin, Ghana
1788						7.6	1.7					5.7	8			AMB	Agunah/Togo, Abomey/Benin
1836	12					5.1	-1.3					6.3	6.5			AMB	Cape Coast, Ghana
1858						5.6	-0.2					6.6	6			AMB	Accra, Ghana
1861						6	0					6.6	5			AMB	Akropong Akwapim, Ghana
1862	7	10	8	15		7	0.4					6.6	9	700		AMB	Kpando, Ghana
1870	11	23	12			5.3	-0.7					4.6	5			AMB	Apam, Ghana
1871	1	26	20			5.5	-0.4					4.7	6			AMB	Accra, Ghana
1872	4	14	23			5.5	-0.4					5.0	7			AMB	Accra, Ghana
1879	2	11	6			6.5	-3.3					5.8	8	380		AMB	Abidjan-Cote d'Ivoire
1883	8	13	2	30		5.5	-0.4					4.7	6	150		AMB	Accra, Ghana
1889	4	5	12	20		5.9	-0.2				4		4			AMB	Amanokrom, Ghana
1894						5.5	-0.2					4.3	3.5			AMB	Accra, Ghana
1906	11	20	21	0		6.5	0.3	12				5.1	7.5	250		ALY	Near Ho-Ghana
1907	2	27	22	15		6.1	-0.9				4.1		4			AMB	Kade, Ghana
1910	12	25				5.6	-0.2					4.0	5			AMB	Accra, Ghana
1911	6	17	15	20		5.5	-0.2					4.0	4			AMB	Accra, Ghana

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
1912						5.5	-3.6					4.0	4			AMB	Near Alepe, Cote d'Ivoire
1930	10	14				7.1	0.7				3.5		4			AMB	Kpalime, Agu-Togo
1933	1	6	4			7	0.6				4		6	100		AMB	Kpalime, Misahoe-Togo
1935	5	29				6.9	0.6					4.8	6			AMB	Near Kpalime, Togo
1939	6	22	19	19	26	5.4	-0.25	18				6.4	8	680		ALY	Coast of Accra, Ghana
1939	8	18	4	51	14	6.2	-0.3					5.4	6			AMB	Koforidua, Ghana
1948						6.2	0.4					4.4	4			AMB	Atimpoku, Ghana
1950	4	4	22	9		6.8	-4.6				4		4			AMB	Dimbroko-Cote d'Ivoire
1950	10	20	15	21	45	7.5	0.5					4.0	4			AMB	Kadjebi-Togo
1964	3	11	12	45	56	5.9	-0.39				4.4		6			AMB	Amasaman, Ghana
1966						5.58	-0.35					4.6	4	10		ALY	Weija, Ghana
1969	2	9	18	29	4	5.5	-0.2	17				4.9	5.5	190		ALY	Accra, Ghana
1973	8	23	17	15		5.7	0.3		2.4							GSD	Offshore-Lepongune
1973	11	28	11	33	21	7	0.8		1.9							GSD	Forêt du Mont Haito, Togo
1974	1	11	5	29	52	5	-2.6					3.6				GSD	Near Beku, Western Ghana
1974	1	16	17	8	50	6.5	0.5		1.9							GSD	Kalakpa Game Production Reserve, Near T
1974	2	20	3	13	43	5	-2.6					3.1				GSD	Near Beku, Western Ghana
1974	6	2	23	15	9	5.8	0.8					2.6				GSD	Jogbove, Ghana
1974	6	8	15	3	5	5.1	2.5					3.4				GSD	Togo
1977	2	2	2	56		5.77	-0.2									GSD	Pokuase, Ghana
1977	2	25	1	19		6.02	-0.2					2.5				GSD	In the Gulf of Guinea, Near Togo

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
1977	3	1	20	50		5.72	-0.2					2.7				GSD	Pokuase, Ghana
1977	3	1	20	58		5.58	-0.28		1.9							GSD	Oblogo, Ghana
1977	4	15	23	46		5.95	-0.07		2.4							GSD	Akropong, Ghana
1977	4	29	18	23		5.67	-0.2					2.5				GSD	Pokuase, Ghana
1977	6	18	4	17		5.63	0.02		2.1							GSD	Prampram, Ghana
1977	7	20	19	34		5.65	-0.28		2							GSD	Pokuase, Ghana
1977	7	26	9	15		5.57	-0.38		2.4							GSD	Weija, Ghana
1977	10	8	3	15		5.97	-0.03					2.8				GSD	Adukrom, Ghana
1977	11	18	23	11		5.58	-0.38		2.2							GSD	Weija, Ghana
1977	11	23	22	9		6	0.12		2							GSD	Agomeda, Ghana
1978	2	7	1	44		6.58	0.13					2.8				GSD	Peki, Ghana
1978	3	3	5	35		5.53	-0.38					3.0				GSD	Near Ngleshi Amanfro, Ghana
1978	7	6	18	10		6.6	0.27		2							GSD	Near Adzokoe, Ghana
1978	9	5	22	59	30	5.63	-0.35					3.7	4			AMB	Weija, Ghana
1978	9	6	12	39		5.63	-0.35		2.1							GSD	Weija, Ghana
1978	9	21	1	22		5.53	-0.4		1.9							GSD	Nyanyanu, Ghana
1978	12	2	11	10		5.53	-0.37		1.9							GSD	Kokrobite, Ghana
1979	1	9	13	58	53	5.58	-0.32					3.4	3.5			AMB	Oblogo, Ghana
1979	1	25	9	0		5.5	-0.33		2.2							GSD	Kasoa, Ghana
1979	3	9	20	16		5.57	-0.38		2.2							GSD	Weija, Ghana

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
1979	3	15	17	37		5.52	-0.35		2.3							GSD	Botianor, Ghana
1979	6	18	18	51		5.5	-0.42		1.9							GSD	Odupomkpehe, Ghana
1979	6	27	20	26		5.53	-0.43		2.1							GSD	Obutu, Ghana
1979	6	28	21	54		5.77	-0.28		1.9							GSD	Doboro, Ghana
1987	7	7	8	11	56	5.44	-0.4					2.7				GSD	Offshore-Nyanyanu
1987	7	31	23	52	4	5.67	-0.26		1.9							GSD	Pokuase, Ghana
1987	12	3	0	29	48	5.51	-0.26					3.0				GSD	Offshore-Labadi, Ghana
1987	12	3	10	37	38	5.53	-0.41					3.0				GSD	Obutu, Ghana
1988	2	27	0	51	4	5.5	-0.4					3.2				GSD	Kasoa, Ghana
1988	3	6	12	15	8	5.63	-0.27		1.9							GSD	Pokuase, Ghana
1988	3	20	19	9	50	5.56	-0.3		1.9							GSD	Oblogo, Ghana
1988	3	25	1	0	35	5.6	-0.28		2							GSD	Weija, Ghana
1988	3	29	16	54	4	5.6	-0.11					3.3	4			ISC	Legon-Accra, Ghana
1988	4	24	13	18	46	5.61	-0.31		1.9							GSD	Kwashiman, Ghana
1988	5	6	1	48	43	5.6	-0.32		2.1							GSD	Oblogo, Ghana
1988	5	31	7	35	8	5.45	-0.37		2.3							GSD	Offshore-Nyanyanu, Ghana
1988	12	5	5	12	43	5.48	-0.4		2.4							GSD	Offshore-Nyanyanu, Ghana
1989	3	23	13	32	47	5.59	-0.33		1.9							GSD	Kwashiman, Ghana
1989	6	27	18	28	9	5.31	-0.6		2.1							ISC	Offshore-Winneba, Ghana
1990	2	12	1	34	41	5.61	-0.34					2.6				NEI	Weija, Ghana
1990	4	14	11	43	26	5.59	-0.34					2.9	3			GSD	Weija, Ghana

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
1990	9	15	9	32	1	5.4	-0.55					3.3				GSD	Offshore-Winneba, Ghana
1990	12	2	0	23	21	5.44	-0.41					2.6				GSD	Offshore-Winneba, Ghana
1991	1	1	7	58	8	5.93	-0.12		2.3							GSD	Akropong, Ghana
1991	3	6	14	54	33	5.61	-0.3		2.1							GSD	Weija, Ghana
1991	3	6	16	50	33	5.62	-0.31		2.3							GSD	Weija, Ghana
1991	3	27	22	18	2	5.64	-0.29					2.9				GSD	Weija, Ghana
1991	6	30	20	44	18	5.62	-0.35		2.3							GSD	Weija, Ghana
1991	8	23	9	51	6	5.62	-0.33					3.7				GSD	Weija, Ghana
1991	10	23	0	14	12	5.53	-0.35		2.3							GSD	Weija, Ghana
1993	4	3	22	33	10	5.5	-0.27		2.1							GSD	Offshore-Nyanyanu, Ghana
1993	4	6	14	29	38	1.3	1.62					4.2				ISC	In the Gulf of Guinea, near Benin
1993	5	7	1	40	46	5.53	-0.23		2.3							GSD	Offshore-Botianor, Ghana
1993	6	22	14	55	39	5.63	-0.56		2.3							GSD	Obrachere, Ghana
1993	6	27	3	38	23	5.53	-0.27					2.7				GSD	Botianor, Ghana
1993	6	28	5	49	3	5.59	-0.32		2.4							GSD	Weija, Ghana
1993	7	17	15	59	59	4.05	-2.44					2.7				ISC	Gulf of Guinea
1993	9	8	3	52	39	5.52	-0.34		2.1							GSD	Offshore-Nyanyanu, Ghana
1993	10	7	18	17	10	5.55	-0.36		2.3							GSD	Weija, Ghana
1993	10	28	10	8	2	5.5	-0.34		2.1							GSD	Offshore-Nyanyanu, Ghana
1994	1	15	19	51	41	5.38	-0.34					2.5				GSD	Nyanyanu, Ghana
1994	1	17	5	49	27	5.47	0.55		2.3							GSD	Brofo Yeduro, Ghana

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
1994	1	27	18	28	1	5.6	-0.27		2.4							GSD	Offshore-Botianor, Ghana
1994	8	26	12	48	20	5.47	-0.27		2							GSD	Botianor, Ghana
1994	8	28	9	44	25	5.36	-0.32		1.9							GSD	Nyanyanu, Ghana
1994	9	6	1	1	4	5.52	-0.37		2.3							GSD	Odupomkpehe, Ghana
1994	9	6	17	30	54	7.65	-3.48					2.8				ISC	Cote d'Ivoire, Ghana
1994	9	6	17	32	8	5.53	-0.42		2							GSD	Obutu, Ghana
1994	10	22	12	4	2	5.6	-0.4		1.9							GSD	Nyanyanu, Ghana
1994	11	10	9	38	3	5.54	-0.35		2.3							GSD	Oblogo, Ghana
1994	12	7	1	21	7	5.52	-0.25		2							GSD	Odupomkpehe, Ghana
1995	1	27	19	16	16	5.45	-0.3		2.2							GSD	Offshore-Botianor, Ghana
1995	1	28	20	22	0	5.6	-0.28		2.3							GSD	Botianor, Ghana
1995	1	28	20	33	14	5.6	-0.36		2.3							GSD	Oblogo, Ghana
1995	1	28	20	39	14	5.55	-0.4					3.2	3			GSD	Weija, Ghana
1995	2	1	3	44	17	5.63	-0.57					2.5				GSD	Obrachere, Ghana
1995	2	1	3	45	20	5.63	-0.45					3.6				GSD	Obrachere, Ghana
1995	2	1	3	58	39	5.6	-0.32					2.6				GSD	Oblogo, Ghana
1995	3	9	18	55	18	5.58	-0.33					3.2	3			GSD	Weija, Ghana
1995	5	3	19	34	1	5.55	-0.3					2.5				GSD	Oblogo, Ghana
1995	6	27	23	43	0	5.52	-0.26		2.4							GSD	Offshore-Botianor, Ghana
1995	10	12	1	8	35	5.5	-0.24					2.5				GSD	Offshore-Botianor, Ghana
1995	10	27	20	1	33	5.5	-0.35					3.8				GSD	Offshore-Kokrobite, Ghana

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
1996	2	22	9	14	39	5.58	-0.45					3.4				GSD	Teshie, Ghana
1996	2	23	9	15	7	5.28	-1.42					2.8				ISC	Komenda, Ghana
1996	7	5	7	42	36	5.43	-0.34					3.0				GSD	Offshore-Botianor, Ghana
1996	8	2	22	37	26	5.44	-0.48		2.4							GSD	Fete, Ghana
1996	8	2	9	26	32	5.44	-0.47		2.3							GSD	Fete, Ghana
1996	8	2	21	1	18	5.52	-0.49		2.4							GSD	Obutu, Ghana
1996	8	31	3	4	59	5.44	-0.43					2.9				GSD	Offshore-Fete, Ghana
1996	9	12	15	15	23	5.62	-0.27		2.3							GSD	Pokuase, Ghana
1996	9	21	18	1	42	5.47	-0.27		2.4							GSD	Offshore-Botianor, Ghana
1996	10	8	12	1	36	5.67	-0.32		2.2							GSD	Manhea, Ghana
1996	10	21	14	19	10	5.82	-0.35					3.2				GSD	Nsawam, Ghana
1997	1	8	9	35	37	5.63	-0.34		2.1							GSD	Weija, Ghana
1997	2	14	23	26	7	5.66	-0.43					2.6				GSD	Dantsera, Ghana
1997	2	14	23	29	5	5.67	-0.4					3.9	4.5			GSD	Manhea, Ghana
1997	3	6	15	59	36	5.6	-0.38		2.2							GSD	Manhea, Ghana
1997	3	6	16	17	0	5.65	-0.38		1.9							GSD	Manhea, Ghana
1997	3	13	18	54	52	5.65	-0.34		2.2							GSD	Weija, Ghana
1997	3	13	0	55	35	5.62	-0.34		2							GSD	Weija, Ghana
1997	3	27	14	29	5	5.62	-0.34		2.3							GSD	Weija, Ghana
1997	9	24	3	2	3	5.6	-0.33		2.3							GSD	Weija, Ghana
1998	1	27	14	4	42	5.75	0.01		2							AMP	Katamanso, Ghana

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
1998	11	19	0	5	2	5.72	0.28		2							AMP	Offshore-Old Ningo, Ghana
1998	11	25	21	14	10	5.77	0.18		2.3							AMP	Offshore-Gulf of Guinea
1998	12	23	16	15	23	5.25	-0.22		2							AMP	Offshore-Nyanyanu, Ghana
1999	1	20	4	53	34	5.35	0		2.2							AMP	Offshore-Tema, Ghana
1999	5	19	15	11	43	5.79	-0.25					2.5				AMP	Abokobi, Ghana
1999	8	22	23	35	29	6.1	-1.29					2.6				AMP	Ochereso, Ghana
1999	10	30	10	21	39	5.79	0.29		2.4							AMP	Offshore-Old Ningo, Ghana
2000	1	30	14	58	19	5.3	-0.32		2.3							AMP	Offshore-Labadi, Ghana
2000	4	17	6	29	23	6.59	0.48		2.1							AMP	Akuse, Ghana
2000	6	8	21	38	38	5.32	-0.01		2.3							AMP	Labadi, Ghana
2000	7	9	20	39	28	5.48	-0.14		2.1							AMP	Aburi, Ghana
2000	8	14	0	2	42	5.78	-0.15					2.5				AMP	Oyarifa, Ghana
2000	9	2	18	27	11	5.59	-0.86		2.2							AMP	Odoben, Ghana
2000	11	8	8	18	29	5.66	2.6					2.6				AMP	Offshore-Prampram, Ghana
2000	11	26	10	26	32	5.54	0.13					3.1				AMP	Offshore-Tema, Ghana
2000	12	8	21	18	45	5.83	-0.24					2.7				AMP	Aburi, Ghana
2001	9	22	8	58	34	5.56	0.18		2.2							AMP	Offshore-Kpong, Ghana
2002	2	21	6	28	35	5.6	0.13					2.7				AMP	Offshore-Tema, Ghana
2002	2	22	2	14	34	5.4	-0.5					2.8				AMP	Senya-Breku, Ghana
2002	5	17	13	37	11	5.6	0.1		2.2							AMP	Offshore-Tuba, Ghana
2002	6	7	1	31	22	5.65	-0.27		2.3							AMP	Oblogo, Ghana

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2002	6	7	1	35	40	5.5	-0.3					3.0				AMP	Offshore-Botianor, Ghana
2002	11	27	5	32	27	5.55	0.5		2							AMP	Offshore-Tema, Ghana
2002	11	29	16	43	43	5.25	-0.6		2							AMP	Offshore-Winneba, Ghana
2003	5	18	6	51	16	5.57	-0.32					2.9				AMP	Weija, Ghana
2003	5	18	7	2	14	5.58	-0.32		2.2							AMP	Weija, Ghana
2003	5	18	13	18	24	5.57	-0.38					2.6				AMP	Weija, Ghana
2003	6	22	6	8	10	6.7	-1.9	2				2.9			86	ISC	Kumasi-Sunyani Road, Ghana
2004	4	17	13	21	13	5.3	-2.6	2				3.2			115	ISC	Elubo-Enchi Road, Ghana
2004	7	2	9	30	33	7.4	-7.1	2				3.2			114	ISC	Man-Cote d'Ivoire
2005	9	29	16	39	18	3.7	-6.3	2				3.4			26	ISC	North Atlantic Ocean-Near Cote d'Ivoire
2007	3	6	0	4	25	5.7	-6.9	50				3.9			68	ISC	Tai National Park, Cote d'Ivoire
2008	6	9	21	48	51	4.6	-3.9	50				4.2			150	ISC	Gulf of Guinea, Cote d'Ivoire
2008	6	26	4	51	42	6.2	-4.7	20				4.2			140	ISC	Tiassale-Cote d'Ivoire
2008	8	16	11	31	49	9.2	-1.5	30				4.2			100	ISC	Daboya-Busunu Road, Ghana
2009	9	11	3	10	19	6.7	2.2	10		4.4					165	ISC	Cotonou-Porto-Novo area, Benin
2009	10	23	10	31	35	9.4	-2.4	30				4.4			41	ISC	Near Mole National Park, Ghana
2009	12	12	18	8	6	7.0	-1.9	2				4.4			80	ISC	Near Kumasi, Ghana
2010	9	30	5	53	31.45	7.3	-2.1					4.4			142	NDC	Nkinkanso, Ghana
2010	10	3	16	15	39.31	11.8	0.1		2.4						138	NDC	Saltenga, Burkina Faso
2010	10	3	22	38	23.41	6.4	-6.2			4.1					157	NDC	Guguha, Cote d'Ivoire
2010	10	30	1	40	31.7	5.6	-5.8			4.0					139	NDC	Gogue, Cote d'Ivoire

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2010	11	4	1	12	38.13	6.7	-4.9			4.1					154	NDC	Angouakoukro, Dimbokro, Cote d'Ivoire
2010	11	4	15	41	15.38	11.8	1.0			4.2					107	NDC	Alondigwena, Burkina Faso
2010	11	7	3	4	49.12	10.7	0.0			3.9					124	NDC	Dore, Northern Togo
2010	11	10	3	24	24.44	7.1	-6.1			4.2					20	NDC	Bafla, Cote d'Ivoire
2010	11	10	3	56	32.03	1.1	-3.1			4.3					173	NDC	Near coast of Ghana / Cote d'Ivoire
2010	11	14	8	8	36.25	6.7	-4.5			4.0					121	NDC	Banngokro, Cote d'Ivoire
2010	11	17	22	33	42.48	-7.5	-13.3			4.6					104	NDC	In the South Atlantic ocean
2010	11	20	5	11	59.15	8.7	-4.6			4.1					110	NDC	Kapolokoro, Cote d'Ivoire
2010	11	21	2	52	46.99	11.8	3.1			4.3					19	NDC	Boiffo, Benin
2010	11	22	7	22	20.93	7.3	-4.3			4.4					128	NDC	Angoakro, Cote d'Ivoire
2010	11	22	9	25	59.82	6.8	-7.6			3.9					25	NDC	Moyen-Cavally, d'Ivoire
2010	11	25	5	42	4.59	6.2	-6.0			2.8					159	NDC	Fromager, Barouyo, Cote d'Ivoire
2010	11	26	21	1	6.94	5.3	-2.4			3.8					19	NDC	Kwesikrom, Western Region, Ghana
2010	11	26	23	59	56.07	12.0	0.9			4.1					117	NDC	Boumwana, Burkina Faso
2010	11	30	4	49	33.64	6.7	-4.4			4.1					110	NDC	Nzi-Commoe, Aoussoukro, Cote d'Ivoire
2010	11	30	20	42	34.93	5.8	-4.9			4.3					100	NDC	Su-Bandama, Guiguedou, Cote d'Ivoire
2010	12	1	16	5	44.72	7.3	-6.1			4.2					8	NDC	Marahou, Zeizra, Cote d'Ivoire
2010	12	2	11	8	48.66	14.2	0.3			4.3					59	NDC	Arbinda, Burkina Faso
2010	12	3	13	22	56.26	12.7	1.0			4.1					159	NDC	Foadyendyengou, Burkina Faso
2010	12	3	15	34	11.82	7.8	-5.6			4.1					112	NDC	Vallee du Bandama, Cote d'Ivoire
2010	12	4	17	3	29.08	13.6	0.5		2.3						18	NDC	Sahel, Burkina Faso

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2010	12	5	1	7	29.27	12.7	0.4			4.0					48	NDC	Louauga, Burkina Faso
2010	12	6	4	49	41.01	7.7	-3.9			3.8					125	NDC	Nzi-Commoe, Kotobo, Cote d'Ivoire
2010	12	9	4	10	6.26	6.5	-5.3			4.1					84	NDC	Fromager, Cote d'Ivoire
2010	12	11	4	59	17.66	6.5	-5.1			4.2					145	NDC	Lacs, Cote d'Ivoire
2010	12	12	18	11	44.21	10.6	-3.1			3.8					74	NDC	Sud-Ouest, Nako, Burkina Faso
2010	12	17	5	56	31.17	6.7	-4.8			4.2					12	NDC	Dimbokro, Cote d'Ivoire
2010	12	22	4	3	43.48	-4.8	-11.8			4.3					141	NDC	Off the coast of Liberia / Cote d'Ivoire
2010	12	22	4	6	37.05	5.8	-5.1			4.6					124	NDC	Ble, Cote d'Ivoire
2010	12	29	7	12	58.47	1.7	-3.2			4.3					144	NDC	Near Coast of Ghana / Cote d'Ivoire
2010	12	29	12	42	32.37	12.2	0.6			4.0					133	NDC	Koulmyougou, Burkina Faso
2010	12	31	10	18	38.13	5.7	-4.4			4.1					82	NDC	Yaobam, Cote d'Ivoire
2011	1	7	20	48	41.71	10.1	-2.8			4.1					109	NDC	Bopiel, Burkina Faso
2011	1	9	10	24	48.64	-1.2	-18.0			4.3					136	NDC	Off the Coast of West Africa
2011	1	10	2	29	59.1	-0.5	-5.4			4.2					93	NDC	Off the Coast of Abidjan, Cote d'Ivoire
2011	1	11	15	41	42.68	-8.4	-5.2			4.3					92	NDC	South Atlantic Ocean, Near Ghana
2011	1	14	12	56	43.87	3.7	-5.4			4.4					90	NDC	Near Coast of Abidjan, Cote d'Ivoire
2011	1	15	3	18	43.86	12.2	-1.1			4.2					3	NDC	Plateau - Central Region, Burkina Faso
2011	1	15	10	51	0.96	5.8	-6.0			4.1					147	NDC	Seryo, Cote d'Ivoire
2011	1	17	2	3	38.94	11.8	2.0			4.2					127	NDC	Logbobou, Burkina Faso
2011	1	17	19	0	29.82	-5.5	-4.5			4.3					131	NDC	South Atlantic Ocean, Near Cote d'Ivoire
2011	1	21	19	4	6.19	6.2	-6.1			4.0					167	NDC	Menekie, Cote d'Ivoire

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2011	1	26	15	43	58.1	6.1	-6.0			3.9					157	NDC	Bogrenyoa, Cote d'Ivoire
2011	1	26	17	35	18.57	6.6	-4.8			4.1					131	NDC	Assebrakro, Cote d'lvoire
2011	1	26	23	9	59.14	5.3	-4.7			4.3					179	NDC	Baiede Cosron, Cote d'Ivoire
2011	1	27	5	28	7.3	6.7	-4.8			4.3					145	NDC	Assebrakro , Cote d'Ivoire
2011	1	27	10	54	46.54	8.0	-4.5			4.1					110	NDC	Vallee du Bandama, Cote d'Ivoire
2011	1	30	14	3	54.04	5.3	-4.7			4.2					72	NDC	Baie de Cosrou, Cote d'Ivoire
2011	1	31	1	57	51.28	1.4	0.3			4.2					62	NDC	South Atlantic Ocean, Near Ghana.
2011	1	31	3	13	23.99	6.4	-4.6			4.0					141	NDC	Menou, Cote d'Ivoire
2011	1	31	15	33	7.21	4.9	-1.6			3.8					123	NDC	Anoe, Sekondi Takoradi, Ghana
2011	2	3	6	1	5.72	0.0	1.6			4.1					100	NDC	Off Coast of Ghana / Togo
2011	2	3	8	4	52.7	11.9	-4.4			2.3					132	NDC	Kouka, Burkina Faso
2011	2	10	19	10	59.31	7.3	-3.6			3.7					144	NDC	Komoe-Denou, Cote d'Ivoire
2011	2	12	17	59	58.76	12.5	1.2			4.3					133	NDC	Boulmomgo, Burkina Faso
2011	2	16	20	16	14.74	6.1	-6.1			3.3					158	NDC	Bakeyo, Cote d'Ivoire
2011	2	16	23	34	37.64	7.4	-3.6			4.2					142	NDC	Katimasso, Cote d'Ivoire
2011	2	17	0	17	33.89	5.7	-5.8			3.7					143	NDC	Gague, Cote d'Ivoire
2011	2	17	6	26	29.86	6.7	-4.8			4.2					148	NDC	Bofrebo, Cote d'Ivoire
2011	2	17	13	40	20.78	6.8	-6.3			4.0					158	NDC	Bebouo, Cote d'Ivoire
2011	2	19	9	22	49.37	5.8	-5.4			4.5					141	NDC	Divo, Cote d'Ivoire
2011	2	23	17	50	37.19	4.3	-5.0			4.2					117	NDC	Near the coast of Abidjan, Cote d'Ivoire
2011	2	23	19	4	15.46	6.2	-6.1			3.7					158	NDC	Bodounyoa, Cote d'Ivoire

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2011	2	24	8	40	11.74	3.0	-3.3			4.4					53	NDC	Near the Coast of Abidjan, Cote d'Ivoire
2011	2	28	18	39	14.13	5.9	-1.8			4.1					172	NDC	Buabenso, Central Region, Ghana
2011	3	1	00	47	9.55	6.8	-4.7			4.2					54	NDC	Koffi Aoussoukro, Cote d'Ivoire
2011	3	01	02	01	4.73	-5.4	-10.9			4.1					127	NDC	Off the Coast of Liberia / Cote d'Ivoire
2011	3	01	03	46	29.91	-5.5	-11.1			4.3					142	NDC	off the coast of Liberia / Cote d'Ivoire
2011	3	01	12	32	2.02	5.3	-5.0			4.2					105	NDC	Tiebiessou, Cote d'Ivoire
2011	3	02	13	09	31.95	5.7	-5.9			4.5					173	NDC	Solouriberipalehoin, Cote d'Ivoire
2011	3	07	00	35	3.37	-8.3	-2.6			3.9					51	NDC	Off the Coast of Cote d'Ivoire / Ghana
2011	3	09	04	53	54.31	8.1	-4.9			4.2					55	NDC	Tinbokoro, Cote d'Ivoire
2011	3	09	05	45	40.52	6.9	1.2			4.2					122	NDC	Kpele, Togo
2011	3	10	13	52	13.60	1.1	1.3			4.0					104	NDC	Near the Coast of Ghana / Togo
2011	3	10	17	45	49.75	6.2	-5.7			3.9					146	NDC	Laouda, Cote d'Ivoire
2011	3	12	05	54	21.62	3.7	-3.4			4.3					102	NDC	Near Coast of Abidjan, Cote d'Ivoire
2011	3	13	23	16	7.57	4.8	-5.4			4.2					114	NDC	Near the Coast of Abidjan, Cote d'Ivoire
2011	3	14	09	31	24.29	6.8	-4.9			4.2					154	NDC	Tokre-Yoakro, Cote d'Ivoire
2011	3	16	09	58	17.23	6.0	-3.3			4.3					146	NDC	Ebikokorekrou, Cote d'Ivoire
2011	3	16	13	18	29.11	6.2	-3.5			4.0					3	NDC	Mbasso, Cote d'Ivoire
2011	3	18	04	32	52.98	5.6	-4.0			3.9					55	NDC	Brou Asse, Cote d'Ivoire
2011	3	18	17	12	40.26	12.7	-3.7			3.7					9	NDC	Biss, Burkina Faso
2011	3	19	11	34	6.39	12.6	0.9			4.2					150	NDC	Nyamanga, Burkina Faso
2011	3	21	16	20	32.21	5.3	-4.2			4.4					71	NDC	Songon-M'bratte, Cote d'Ivoire

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2011	3	22	13	34	28.95	5.3	-5.5			4.2					113	NDC	Mokta, Cote d'Ivoire
2011	3	22	13	40	2.49	12.4	0.9			4.5					24	NDC	Kankantiana, Burkina Faso
2011	3	22	16	52	6.66	3.2	-0.7		2.9						64	NDC	Gulf of Guinea, Near the Coast of Sekondi
2011	3	23	08	16	46.92	8.4	-6.4		2.0						62	NDC	Kasatou, Cote d'Ivoire
2011	3	24	07	07	31.79	8.4	-5.4			3.9					70	NDC	Kafine, Cote d'Ivoire
2011	3	26	02	16	36.34	6.6	-4.9			3.8					34	NDC	Dimbokro, Cote d'Ivoire
2011	3	26	04	06	48.21	6.4	-5.1			4.2					123	NDC	Bringakro, Cote d'Ivoire
2011	3	27	08	21	30.69	7.2	-3.1			4.2					151	NDC	Kokomia, Cote d'Ivoire
2011	3	29	16	56	8.87	8.6	-2.3			4.3					120	NDC	Tinga, Northern Region, Ghana
2011	4	1	10	25	11.56	6.7	-4.8			4.0					88	NDC	Bofrbo, Cote d'Ivoire
2011	4	1	16	46	27.96	11.9	0.2			3.8					128	NDC	Kouare, Burkina Faso
2011	4	2	6	46	19.72	7.0	-2.5			4.2					171	NDC	Mim, Brong Ahafo Region, Ghana
2011	4	2	23	2	41.55	5.9	-5.9			4.1					142	NDC	Niali-Gribouo, Cote d'Ivoire
2011	4	3	14	29	32.08	10.0	0.0			4.2					45	NDC	Nagale, Northern Region, Ghana
2011	4	3	17	23	7.82	-9.5	-2.7			4.3					116	NDC	South Atlantic Ocean, Near ghana.
2011	4	3	22	44	43.95	6.5	0.7			3.8					137	NDC	Agotime Kpetoe, Volta Region, Ghana
2011	4	4	2	17	20.5	6.1	-6.2			4.4					180	NDC	Kripayo, Cote d'Ivoire
2011	4	7	5	20	49.58	4.1	-5.0			4.0					119	NDC	Near the Coast of Abidjan, Cote d'Ivoire
2011	4	8	21	26	57.97	6.6	-4.6			4.4					124	NDC	Frondobo, Cote d'Ivoire
2011	4	10	20	6	40.66	6.3	-3.7			3.9					14	NDC	Ananguie, Cote d'Ivoire
2011	4	14	5	32	52.34	16.2	-6.3			3.9					31	NDC	Natabouanga, Burkina Faso

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2011	4	14	13	55	18.82	12.5	0.5			4.0					150	NDC	Natabouanga, Burkina Faso
2011	4	16	14	6	31.37	6.7	-4.9			2.4					133	NDC	Angouakoukro, Cote d'Ivoire
2011	4	17	9	46	36.76	13.0	1.4			4.1					168	NDC	Dimbokro, Cote d'Ivoire
2011	4	17	11	45	15.93	7.0	-4.8			3.9					3	NDC	Angouakoukro, Cote d'Ivoire
2011	4	18	14	13	18.97	6.0	-5.2			4.3					100	NDC	Zehiri, Cote d'Ivoire
2011	4	19	18	34	59.37	5.3	-4.4			4.3					70	NDC	Dabou, Cote d'Ivoire
2011	4	20	0	37	18.21	7.5	-5.0			4.0					83	NDC	Kouabo, Cote d'Ivoire
2011	4	23	11	36	28.61	5.4	-5.4			4.3					133	NDC	Niakro, Cote d'Ivoire
2011	4	25	9	9	38.33	6.8	-5.5			4.3					176	NDC	Boanfla, Cote d'Ivoire
2011	4	25	22	36	55.68	10.3	-0.6		2.2						134	NDC	Bazai, Cote d'Ivoire
2011	4	26	22	2	45.6	6.7	-4.8			3.8					59	NDC	Angouakoukro, Cote d'Ivoire
2011	5	06	20	07	38.97	1.1	-5.9			3.9					89	NDC	Gulf of Guinea, Near cote d'Ivoire
2011	5	07	01	49	34.79	6.0	-3.8			4.0					28	NDC	Adzope, Cote d'Ivoire
2011	5	09	06	27	22.32	12.8	1.3			4.2					140	NDC	Est. Burkina Faso
2011	5	10	23	17	53.08	5.9	-5.3			4.3					133	NDC	Cote d'Ivoire
2011	5	15	05	26	40.09	4.5	-1.3			4.4					126	NDC	Gulf of Guinea, Near Ghana
2011	5	16	21	29	15.76	4.8	-5.2			4.1					115	NDC	Gulf of Guinea, Near Cote d'Ivoire
2011	5	19	03	32	25.01	5.4	-5.4			4.0					95	NDC	Cote d'Ivoire
2011	5	19	20	22	58.34	6.6	-4.9			4.2					39	NDC	Cote d'Ivoire
2011	5	21	07	37	5.48	6.3	-4.6			4.1					146	NDC	Nzi-Comoe, Cote d'Ivoire
2011	5	22	03	12	10.95	6.2	-5.3			4.3					145	NDC	Sud-Bandama, Cote d'Ivoire

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2011	5	25	15	31	15.76	8.0	-3.7			4.2					125	NDC	Cote d'Ivoire
2011	5	29	04	45	5.14	6.6	-4.7			4.1					100	NDC	Cote d'Ivoire
2011	5	29	10	02	54.91	14.1	0.1			4.0					21	NDC	Burkina Faso
2011	5	30	22	45	15.35	6.6	-4.8			3.9					138	NDC	Cote d'Ivoire
2011	6	03	03	68	26.43	6.6	-6.2			4.4					160	NDC	Haut-sassandra Cote d'Ivoire
2011	6	03	06	35	55.56	5.6	-4.4			3.8					74	NDC	Cote d'Ivoire
2011	6	11	22	35	26.63	6.3	-5.2			4.3					130	NDC	Bandama, Cote d'Ivoire
2011	6	12	05	31	53.92	6.8	-5.0			4.2					130	NDC	Lacs, Cote d'Ivoire
2011	6	13	02	40	53.85	13.5	0.7			3.8					61	NDC	Burkina Faso
2011	6	19	08	48	10.30	9.4	-2.7			4.4					128	NDC	Black Volta, Ghana
2011	6	19	10	06	24.80	5.4	-5.2			4.2					103	NDC	Sud-Bandama Cote d'Ivoire
2011	6	23	13	09	10.53	7.5	-2.2			2.4					142	NDC	Odumase Rd Sunyani Ghana
2011	6	25	15	45	14.09	8.6	-5.4			2.2					102	NDC	Cote d'Ivoire
2011	7	03	03	53	33.64	5.6	-2.8			4.4					7	NDC	Omanpe, near Ghana Cote d'Ivoire border
2011	7	06	17	34	31.07	5.3	-5.0			4.2					111	NDC	Lagunes, Cote d'Ivoire
2011	7	08	06	22	34.27	6.1	-4.9			4.1					121	NDC	Singrobo, Cote d'Ivoire
2011	7	08	20	14	48.91	6.5	-3.5			4.1					20	NDC	Akouaba, Cote d'Ivoire
2011	7	09	23	20	59.36	3.0	-5.6			4.6					111	NDC	Near the coast of San-Pedro, Cote d'Ivoire
2011	7	09	23	36	18.67	-11.3	-10.3			4.1					138	NDC	Off the Coast of Liberia/ Cote d'Ivoire
2011	7	10	16	19	54.38	5.3	-4.5			4.4					77	NDC	Dabou, Cote d'Ivoire
2011	7	10	19	12	34.73	10.1	-6.8			3.8					86	NDC	Zaniegue, Cote d'Ivoire

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2011	7	11	06	57	3.72	8.0	-5.1			4.0					103	NDC	Kadyoukaha, Cote d'Ivoire
2011	7	13	08	32	50.26	5.2	-5.0			4.3					109	NDC	Nzida, Cote d'Ivoire
2011	7	15	11	41	49.27	6.6	-4.8			3.9					130	NDC	Dimbokro, Cote d'Ivoire
2011	7	17	18	55	11.58	7.0	-5.7			3.8					37	NDC	Bouafle, Cote d'Ivoire
2011	7	18	17	51	47.11	5.3	-5.2			4.2					106	NDC	Nzida, Cote d'Ivoire
2011	7	22	00	21	26.57	6.0	-4.5			4.1					32	NDC	Rubino, Cote d'Ivoire
2011	7	23	05	23	36.66	7.1	-4.3		2.2						138	NDC	Bocanda, Cote d'Ivoire
2011	7	25	04	43	5.35	-1.0	-7.4			4.1					105	NDC	Off the Coast of Liberia/ Cote d'Ivoire
2011	8	06	12	41	55.52	5.4	-1.8			3.9					6	NDC	Kwakuadjeikrom, W/R. Ghana.
2011	8	07	10	39	11.36	2.5	-5.7			4.3					108	NDC	Near Coast of Cote d'Ivoire
2011	8	08	06	56	31.41	7.7	-3.9			4.3					105	NDC	Koumasso, Cote d'lvoire
2011	8	09	06	21	32.28	6.7	-4.8			4.3					67	NDC	Assesbrakro, Cote d'Ivoire
2011	8	13	23	37	21.11	5.7	-4.2			4.1					64	NDC	Petit Yapo, Cote d'Ivoire
2011	8	14	08	01	0.20	6.5	-4.8			3.3					159	NDC	Guesseguie, Cote d'lvoire
2011	8	17	00	54	34.49	4.2	-5.0			4.4					94	NDC	In the Gulf of Guinea, Cote d'lvoire.
2011	8	17	12	30	9.77	4.4	-4.3			4.1					66	NDC	Near Coast of Cote d'lvoire.
2011	8	17	14	29	14.37	6.1	-6.2			4.0					156	NDC	Konayo, Cote d'Ivoire
2011	8	23	19	16	2.11	12.7	1.4			4.3					31	NDC	Kowari, Burkina Faso
2011	9	01	00	29	11.69	6.8	-6.2			4.2					177	NDC	Dignago, Cote d'lvoire
2011	9	04	12	27	4.63	-2.8	-7.8			4.0					67	NDC	Off the Coast of Cote d'lvoire
2011	9	10	13	09	32.84	5.9	-6.1			3.8					151	NDC	Gohie, Cote d'lvoire

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2011	9	11	06	48	14.70	2.6	-3.0			4.2					109	NDC	Near coast of cote d'lvoire
2011	9	12	18	02	48.37	5.6	-4.0			4.1					114	NDC	Nsakoi, Cote d'lvoire
2011	9	13	08	08	0.57	7.2	-3.6					4.6			154	NDC	Yacasse, Cote d'lvoire
2011	9	14	15	44	54.62	10.8	-4.1			3.9					80	NDC	Moribarasso, Burkina Faso
2011	9	15	20	29	24.94	11.7	2.7			4.5					116	NDC	Guene, Benin
2011	9	20	22	57	7.05	12.2	1.7			4.3					73	NDC	Byati, Burkina Faso
2011	9	21	18	12	47.42	5.3	-4.8			4.4					61	NDC	Tiagba, Cote d'lvoire
2011	9	23	13	21	7.14	-0.8	-5.5			4.3					103	NDC	Off the Coast of Cote d'lvoire
2011	9	23	21	19	58.57	6.1	-6.1			4.3					146	NDC	Kripayo, Cote d'lvoire
2011	9	25	01	29	31.04	6.4	-3.5			4.3					171	NDC	Blekoum, Cote d'lvoire
2011	9	26	05	02	6.07	6.1	-5.1			4.0					92	NDC	Goudi, Cote d'lvoire,
2011	9	27	16	15	24.33	5.6	-4.0			4.1					55	NDC	Nasakoi, Cote d'Ivoire
2011	9	27	19	00	52.98	4.1	-5.6			4.4					74	NDC	Near coast of Cote d'lvoire
2011	9	29	09	39	3.45	3.9	-3.3			3.7					88	NDC	Near coast Cote d'Ivoire.
2011	10	05	09	01	20.39	-0.4	-8.0			4.2					100	NDC	Off the coast of Liberia / Cote d'lvoice
2011	10	07	08	57	10.78	6.5	-5.9			4.2					154	NDC	Bahompa, Cote d'lvoire
2011	10	10	03	03	24.91	7.2	-4.5			4.3					74	NDC	Kokoboukro, Cote d'lvoire
2011	10	11	21	51	48.76	6.2	-2.3			3.9					167	NDC	Sefwi Bekwai, WR. Ghana
2011	10	12	23	14	42.79	13.4	0.9			4.0					9	NDC	Satyouri, Burkina Faso
2011	10	13	03	52	6.63	8.8	-7.1					4.6			41	NDC	Sebedian, Cote d'lvoire
2011	11	05	17	27	13.87	11.7	1.8			4.0					110	NDC	Nampondi, Burkina Faso
2011	11	06	09	01	51.25	6.0	-6.1			4.5					153	NDC	Digbahio, Cote d'lvoire

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2011	11	06	09	12	58.96	12.7	-4.1			4.2					95	NDC	Soumbara, Burkina Faso
2011	11	08	21	08	44.95	12.7	-3.8			4.1					113	NDC	Niankui, Burkina Faso
2011	11	14	06	13	15.63	6.7	-2.3			4.4					161	NDC	Asuako, Ashanti Region, Ghana
2011	11	25	04	43	15.63	11.8	1.4			4.1					95	NDC	Arli National Park, Burkina Faso
2011	11	25	09	31	14.44	6.6	-4.9			4.2					57	NDC	Assebrakro, Cote d'lvoire
2011	11	27	22	18	14.52	7.4	-5.1			4.5					2	NDC	Mbouedio, Cote d'lvoire
2011	11	28	01	29	59.91	6.5	-3.5			3.7					166	NDC	Tanekron, Cote d'lvoire
2011	11	29	11	30	48.52	7.2	-5.4			4.4					22	NDC	Gtogro, Cote d'lvoire
2011	12	03	09	26	8.58	-5.4	-5.6			4.7					136	NDC	off the coast of Cote d'lvoire / Ghana
2011	12	04	08	42	6.94	7.9	-4.3			4.2					117	NDC	Satama - Sokoura, Cote d'lvoire
2011	12	10	01	50	52.86	6.0	-5.0			4.3					91	NDC	Sokogrobo, Cote d'lvoire
2011	12	11	16	40	26.94	7.2	-4.3			4.0					143	NDC	Kamoukouanou, Cote d'lvoire
2011	12	17	20	40	10.21	13.4	0.8			4.1					11	NDC	Satyouri, Burkina Faso
2011	12	26	09	51	58.54	4.4	-4.3			4.5					44	NDC	Near Coast of Abidjan-Cote d'Ivoire
2011	12	26	13	29	45.81	11.8	1.8			4.0					101	NDC	Tombaga, Burkina Faso.
2011	12	27	01	37	58.83	-6.3	-1.5			4.0					47	NDC	Off the Coast of Cote d'lvoire / Ghana.
2011	12	27	09	26	18.89	7.8	-4.2			4.3					122	NDC	Atokonou, Cote d'lvoire
2011	12	31	00	25	19.45	9.1	1.5			4.2					124	NDC	Near Tchanba, Togo
2012	1	03	19	28	11.75	1.8	-0.5			4.3					97	NDC	In the Sea, off Coast of Ghana
2012	1	06	00	20	22.52	0.7	-3.9			4.0						NDC	In the Sea, off Coast of Ivory Coast

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2012	1	06	00	38	51.47	-13.67	-13.8			4.5					120	NDC	In the Sea, off Coast of South Africa
2012	1	11	17	36	37.96	7.7	-6.1			4.0					48	NDC	Kongaso, Cote d'lvoire
2012	1	20	10	07	0.85	7.0	-4.9			3.6					176	NDC	Bocanda, Cote d'lvoire
2012	1	22	19	48	49.53	7.2	2.0			2.1					131	NDC	Bhicon, Benin
2012	1	23	00	21	22.92	8.0	-4.4			4.0					91	NDC	Messarandougou, Cote d'lvoire
2012	1	23	23	27	46.44	7.2	-4.1			3.7					135	NDC	Daoukro, Cote d'lvoire
2012	2	05	01	17	53.46	4.0	-2.5			4.0					149	NDC	Gulf of Gunea, Cote d'Ivoire / Ghana
2012	2	06	00	20	38.89	11.8	2.1			4.0					113	NDC	Burkina Faso National Park, Burkina Faso
2012	2	06	10	12	45.06	3.9	-4.2			4.5					108	NDC	Near Abidjan, Cote d'Ivoire
2012	2	07	16	41	27.01	6.7	-4.9			3.9					92	NDC	Dimbokro, Cote d'lvoire
2012	2	10	22	02	41.90	6.2	-5.4			3.8					137	NDC	Ovime, Cote d'lvoire
2012	2	16	04	16	13.84	5.9	-5.5			4.0					131	NDC	Gabiakok, Cote d'lvoire
2012	2	20	01	52	52.99	6.4	-5.0			4.2					33	NDC	Angbavia, Cote d'lvoire
2012	2	21	00	14	9.92	12.5	-1.7			4.1					123	NDC	Koudouwogen, Burkina Faso
2012	2	22	06	37	57.74	5.8	-4.0			4.6					25	NDC	Agbouille, Cote d'lvoire
2012	2	24	12	40	28.69	6.8	-5.0			4.1					150	NDC	Park National d' Abokonamekro Cote d'lvo
2012	3	10	01	32	43.70	3.0	-4.6			4.2					123	NDC	Near Coast of Abidjan, Cote d'Ivoire
2012	3	10	02	36	37.92	3.5	-0.7			4.2					146	NDC	Near Coast of Accra, Ghana
2012	3	11	03	57	16.50	7.5	-7.2		1.6						91	NDC	Man, Cote d'lvoire
2012	3	12	05	33	20.60	5.3	-4.6			4.1					95	NDC	Dabou, Cote d'Ivoire
2012	3	13	20	01	40.13	14.7	-1.3			3.8					113	NDC	Sahel Reserve, Burkina Faso

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2012	3	14	18	19	51.21	5.5	-5.5			4.2					122	NDC	Borodou, Ivory Coast
2012	3	18	04	57	42.36	7.1	-4.8			4.1					103	NDC	Didievi, Ivory Coast.
2012	3	19	11	05	37.31	0.8	1.5			3.9					143	NDC	Off the Coast of Ghana / Togo
2012	3	20	06	05	7.29	9.9	-3.7		2.7						126	NDC	Kampti, Burkina Faso
2012	3	20	21	30	46.50	6.7	-4.9			3.9					58	NDC	Dimbokro, Cote d'lvoire
2012	3	21	22	36	32.06	-14.4	-4.2			4.4					156	NDC	Off the Coast of Ghana / Togo
2012	3	22	14	41	23.87	7.9	-4.1			4.0					119	NDC	Groumania, Cote d'lvoire
2012	3	23	03	59	9.52	7.1	-5.9			4.3					167	NDC	Bouafle, Cote d'lvoire
2012	3	27	23	32	42.80	12.3	1.4			4.1					106	NDC	Kantchari, Burkina Faso
2012	3	31	10	14	8.98	6.7	-4.9			4.0					12	NDC	Dimboko, Cote d'lvoire
2012	4	01	12	19	16.96	5.3	-4.5			4.0					95	NDC	Toupah, Cote d'lvoire
2012	4	07	06	19	45.99	12.4	1.3			4.0					120	NDC	Nalougou, Burkina Faso
2012	4	11	03	17	36.67	-3.3	-0.3			4.1					103	NDC	Off the Coast of Ghana
2012	4	11	04	05	35.72	-3.9	3.5			4.1					27	NDC	Off the Coast of Benin/Nigeria
2012	4	11	05	44	40.70	-16.8	-14.5			4.4					127	NDC	Off the Coast of Liberia/Cote d'Ivoire
2012	4	13	14	57	17.25	6.8	-4.2			4.3					88	NDC	Kotobi, Cote d'lvoire
2012	4	16	19	05	13.42	7.8	-5.6			3.9					69	NDC	Bandama, Cote d'lvoire
2012	4	16	21	59	47.67	0.4	-10.8			4.2					131	NDC	Off the Coast of Liberia/Cote d'Ivoire
2012	4	17	07	23	51.37	6.4	-6.2					6.2			165	NDC	Sauuia, Cote d'Ivoire
2012	4	17	08	02	21.03	5.3	-4.8			4.1					46	NDC	Bale de Cosrou, Cote d'lvoire
2012	4	19	00	14	58.90	4.2	-4.7			3.7					99	NDC	Near Abidjan, Cote d'Ivoire

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2012	4	20	10	36	49.47	8.6	-5.6			4.1					60	NDC	Niakaramandougou, Cote d'Ivoire
2012	4	24	04	11	41.65	13.5	0.9			4.0					18	NDC	Burkina Faso
2012	4	24	11	06	3.71	13.6	0.9			3.2					81	NDC	Burkina Faso
2012	4	24	19	15	13.57	7.1	-4.2			3.9					136	NDC	Bocanda, Cote d'Ivoire
2012	4	26	22	21	55.70	5.3	-4.6			4.0					87	NDC	laqune Ebrie, Cote d'lvoire
2012	4	27	06	19	43.29	7.0	-7.7			3.9					163	NDC	Bangolo, Cote d'lvoire
2012	4	28	23	26	4.08	6.6	-4.9			4.0					46	NDC	Toumodi, Cote d'Ivoire
2012	5	01	07	00	37.61	13.8	0.4			3.7					51	NDC	Dori, Burkina -Faso
2012	5	03	09	22	51.93	6.5	-4.8			4.2					157	NDC	Dimbokro, Cote d'Ivoire
2012	5	07	12	24	43.55	5.9	-6.6			4.4					167	NDC	Badayo I, Cote d'Ivoire
2012	5	08	13	28	30.59	5.4	-3.0			3.9					11	NDC	Affienou, Cote d'Ivoire
2012	5	08	18	28	59.54	5.9	-4.3			4.3					28	NDC	Offa, Cote d'Ivoire
2012	5	09	14	49	50.37	-1.1	-13.2					6.2			133	NDC	Off Coast of Liberia/Cote d'Ivoire
2012	5	11	16	36	58.82	6.7	-4.9			4.3					58	NDC	Toumodi, Cote d'Ivoire
2012	5	14	03	38	21.48	6.6	-4.8			4.3					145	NDC	Dimbokro, Cote d'Ivoire
2012	5	15	01	33	17.91	-4.9	-11.6			4.1					102	NDC	Off Coast Of Liberia/Cote d'Ivoire
2012	5	17	04	59	5.89	5.9	-4.8			4.2					104	NDC	Tiassale, Cote d'Ivoire
2012	5	18	11	55	6.21	-0.5	-6.7			4.2					127	NDC	Off Coast of Liberia/Cote d'Ivoire
2012	5	18	15	00	52.35	5.8	-6.1			4.2					144	NDC	Gohue, Cote d'Ivoire
2012	5	22	02	36	50.69	6.3	-3.3			4.0					69	NDC	Apopromponou, Cote d'Ivoire
2012	5	25	02	59	58.70	5.3	-2.8			4.3					13	NDC	Kwesinimpa Impa, Cote d'Ivoire

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2012	5	25	17	43	36.45	7.0	-4.2			4.0					77	NDC	Daoukro, Cote d'Ivoire
2012	5	26	11	35	21.52	6.6	-4.8			4.0					127	NDC	Daoukro, Cote d'Ivoire
2012	5	31	17	23	32.63	7.2	-6.7			4.1					8	NDC	Vanona, Cote d'Ivoire
2012	5	31	19	25	57.48	6.6	-4.9			3.9					13	NDC	Dimbokro, Cote d'Ivoire
2012	6	18	16	08	22.64	6.4	-5.4			3.8					57	NDC	Oume,Cote d'lvoire
2012	6	20	00	59	14.49	7.0	2.2		2.5						131	NDC	Foret d Agrime, Benin
2012	6	21	07	26	38.40	7.3	-7.2		2.4						17	NDC	Man, Cote d'lvoire
2012	6	21	22	51	53.60	7.0	-6.0			4.3					18	NDC	Brozra, Cote d'lvoire
2012	7	04	11	38	43.89	8.6	-6.6			4.1					58	NDC	Kani, Cote d'lvoire
2012	7	15	14	20	21.92	7.1	-4.2			4.0					14	NDC	Daoukro, Cote d'lvoire
2012	7	18	16	08	22.64	6.4	-5.4			3.8					57	NDC	Oume, Cote d'lvoire
2012	7	28	06	00	13.51	6.1	-3.6			4.3					1	NDC	Adzope, Cote d'lvoire
2012	7	30	11	16	51.29	6.0	-3.4			3.9					27	NDC	Bettie, Cote d'lvoire
2012	8	4	12	59	22.40	13.0	-4.2			4.2					34	NDC	Djibasso, Burkina Faso
2012	8	4	18	21	2.47	5.4	-4.4					4.8			30	NDC	Orbaff, Cote d'lvoire
2012	8	5	19	11	45.08	11.9	2.4			4.0					83	NDC	Diapaga, Burkina Faso
2012	8	6	13	6	31.78	-2.2	-6.5			4.0					42	NDC	Off the Coast of Liberia/ Cote d'lvoire.
2012	8	6	15	11	11.34	11.2	-3.2		2.9							NDC	Kantchari, Burkina Faso
2012	8	7	11	36	56.91	12.5	1.2			4.3					38	NDC	Kantchari, Burkina Faso
2012	8	9	13	2	11.82	6.7	-4.8			4.4					3.7	NDC	Dimbokro, Cote d'lvoire
2012	8	11	22	2	38.60	6.7	-3.5			4.2					31	NDC	Abengouron, Cote d'lvoire.
2012	8	11	22	47	6.43	5.9	-4.5		2.9						28	NDC	Aboude Mendeke, Cote d'lvoire

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2012	8	18	12	01	25.44	6.0	-3.62			4.2					158	NDC	Adzope, Cote d'Ivoire
2012	8	19	12	18	20.06	11.8	1.7			4.3					74	NDC	Near Tombaga, Burkina Faso
2012	8	21	06	45	56.74	6.2	-3.5					6.2			14	NDC	Near Abengova, Cote d'Ivoire
2012	8	22	08	09	32.32	10.6	-1.9		2.0						135	NDC	Bechembeli, Upper West, Ghana
2012	9	06	12	06	9.16	5.7	-4.8			4.0					96	NDC	Ndouci, Cote d'lvoire
2012	9	17	20	17	21.53	7.7	-5.8			4.1					180	NDC	Beoumi, Cote d'lvoire
2012	9	21	13	09	8.79	5.2	-6.9		2.2						138	NDC	Tai National Park, Cote d'lvoire
2012	9	26	19	25	45.78	6.3	-0.5			4.2					136	NDC	Near Kwabeng, Ghana
2012	10	12	03	53	21.21	4.6	-4.6			4.1					104	NDC	Near the coast of Cote d'Ivoire
2012	10	12	14	27	24.23	5.8	-5.9			4.0					24	NDC	Gueyo, Cote D'lvoire
2012	10	14	05	33	52.49	7.6	-6.5			4.3					30	NDC	Vavoua, Cote D'lvoire
2012	10	23	04	56	4.92	11.8	1.3			4.1					91	NDC	Arli natoinal park, Burkina Faso
2012	10	26	23	29	38.13	8.0	-4.4			4.2					112	NDC	Satama Sokoro, Cote d'Ivoire
2012	10	27	03	40	18.09	6.7	-4.8			3.5					103	NDC	Assebrakro, Cote d'Ivoire
2012	10	27	23	19	43.08	5.6	-4.0			3.9					39	NDC	Atiekoi, Cote d'Ivoire
2012	10	29	14	30	48.63	8.4	-4.3			4.4					106	NDC	Dabakala, Cote d'Ivoire
2012	10	30	09	55	10.53	6.4	-4.3			3.9					114	NDC	Bongouanou, Cote d'Ivoire
2012	10	30	22	00	12.88	0.9	-6.4			4.1					116	NDC	Coast of Cote d'Ivoire
2012	11	02	23	43	07.51	4.8	-2.8			3.8					15	NDC	Gulf of Guinea, Near the Coast of Ghana
2012	11	04	00	30	50.40	12.2	1.8			4.1					95	NDC	Near Touaga, Burkina Faso
2012	11	04	05	11	59.40	12.0	1.2			4.0					119	NDC	Near Singou Reserve, Burkina Faso

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2012	11	07	00	30	17.22	7.1	-5.2			4.0					75	NDC	Near Bomizabo, Cote d'Ivoire
2012	11	07	19	44	21.91	6.6	-6.3			4.4					26	NDC	Near Saouia, Cote d'Ivoire
2012	11	13	10	27	31.19	6.1	-3.8			4.1					19	NDC	Near Adzope, Cote d'Ivoire
2012	11	14	04	43	34.24	8.0	-4.5			4.2					101	NDC	Near Dyaradougou, Cote d'Ivoire
2012	11	20	12	20	26.47	5.4	-4.2			4.2					43	NDC	Near Attinguie, Cote d'Ivoire
2012	11	21	12	21	23.43	6.6	-4.9			4.5					44	NDC	Near Totonou, Cote d'Ivoire
2012	11	25	17	48	53.42	6.8	-5.0			3.7					144	NDC	Near Amandie, Cote d'Ivoire
2012	11	26	01	39	15.61	11.5	0.5			4.0					129	NDC	Near Pama Reserve, Burkina Faso
2012	11	26	08	24	18.81	-2.8	-14.3					5.1			142	NDC	Off the Coast of Liberia
2012	11	27	19	46	52.02	6.2	-4.6			4.4					179	NDC	Rubino, Cote d'Ivoire
2012	11	29	01	17	19.96	5.3	-4.9			3.6					76	NDC	Assagny National Park, Cote d'Ivoire
2012	11	30	01	56	39.94	5.7	-5.8			4.5					99	NDC	Near Gague, Cote d'Ivoire
2012	12	01	13	42	32.09	7.6	-6.3			4.1					30	NDC	Near vavoua, Cote d'Ivoire
2012	12	05	11	30	03.65	6.6	-5.5			4.4					25	NDC	Near Konefia, Cote d'Ivoire
2012	12	06	06	58	51.91	6.8	-7.6			5.1					163	NDC	Near Duekoue, Cote d'Ivoire
2012	12	07	15	34	28.29	14.3	-1.6			4.2					156	NDC	Near Djibo, Burkina Faso
2012	12	07	18	34	35.78	7.3	-0.4			4.5					77	NDC	Near Digya national park, Ghana
2012	12	09	01	35	56.37	3.8	-4.1			4.2					78	NDC	Near the Coast of Cote d'Ivoire
2012	12	09	22	36	23.77	6.7	-4.9			4.2					40	NDC	Near Dimbokro, Cote d'Ivoire
2012	12	12	09	32	48.20	0.8	0.1			4.4					147	NDC	Off the Coast of Ghana
2012	12	13	11	43	02.34	3.7	-1.2			4.8					179	NDC	Near the Coast of Ghana

Yr	M	D	H	Min	Sec	Lat	Lon	Dp	M_L	Mb	MM	Mw	Io	RS	Az	Ref	Location
2012	12	14	08	35	14.63	5.9	-3.6			3.8					165	NDC	Near Abie, Cote d'Ivoire
2012	12	15	04	37	38.55	12.8	1.0			4.0					153	NDC	Near Bossongri, Burkina Faso
2012	12	15	05	00	47.56	-7.4	-14.3			4.6					150	NDC	Off the Coast of Liberia/Cote d'Ivoire
2012	12	16	03	07	46.73	6.4	-5.2			4.1					19	NDC	Near Groudji, Cote d'Ivoire
2012	12	16	03	36	27.45	13.7	-0.2			4.1					3	NDC	Near Bani, Burkina Faso
2012	12	16	14	31	45.04	5.4	-4.3		2.1						51	NDC	Near Le Nieky, Cote de d'Ivoire
2012	12	17	11	46	35.72	0.9	1.5			4.5					22	NDC	Off the Coast of Ghana
2012	12	19	16	04	59.29	6.3	-6.2			4.2					6	NDC	Near Guberoua, Cote d'Ivoire
2012	12	23	13	22	23.88	6.8	-3.5			4.1					148	NDC	Near Zinzenou, Cote d'Ivoire
2012	12	24	12	23	38.81	13.0	-4.3			4.6					150	NDC	Near Mandiakui, Burkina Faso
2012	12	26	13	01	36.89	-3.5	-4.9			4.3					107	NDC	Off the Coast of Cote d'Ivoire/Ghana
2012	12	26	13	47	31.02	4.6	-2.3			4.2					68	NDC	Near the Coast of Ghana

References abbreviation list: ALY (Leydecker, G. and P. Amponsah), New estimation of epicentral intensity and focal depth by macroseismic methods (using formula (1)), based on the isoseismal radii, given by Ambraseys and Adams (1986); AMB, Ambraseys and Adams (1986); AMP, Amponsah (2008); GSD, Geological Survey Department, 7th Avenue, 6, P.O. Box M80, Accra, Ghana. The data for the years 1973–1997 were taken from Amponsah (2002); ISC, International Seismological Centre, Pipers Lane, Thatcham, Berkshire, United Kingdom RG19 4NS; admin@isc.ac.uk; JUN, Junner (1941); NEI, National Earthquake Information Service (NEIS), United States Geological Survey, Denver, Colorado 80225, USA; NDC, National Data Centre of the Ghana Atomic Energy Commission, GAEC.

Description of the parameters in the earthquake catalogue: Yr, year; M, month; D, day; H, hour; Min, minute; Sec, second; Lat, Latitude in degree; North; Long, longitude in degree; negative = West; Dp, focal depth in kilometers; focal depth estimation only with macroseismic data; M_L, local magnitude; MD, duration magnitude; MM, surface wave magnitude, based only on macroseismic data; Mw, moment magnitude; Io, epicentral intensity estimated macroseismically; RS, radius of perceptibility in km; Azimuth; Ref, reference; Location, location of earthquake

5.1.2 SEISMICITY AND EPICENTRAL INTENSITY MAPS

The seismicity map generated clearly defines the frequency of earthquakes, the magnitudes prevalent and the distribution of these magnitudes from 1615 to 2012. The seismicity map of the study area is shown in Figure 5.1. The converted latitudes and longitudes of all the 554 events and their corresponding magnitudes and epicentral intensities are shown in Appendix C. The plot of these computed values is shown in Figure 5.2.

The epicentral intensity map clearly defines the epicentral intensities evaluated. The range of the epicentral intensity computed for the study area is from 3.6 to 8.2 whilst earthquake magnitudes between 4 and 5 are highly present in GAMA. The plot shows areas of high intensities to be western, south western (around Weija) and north eastern Accra (6.02 to 8.6). Other areas include Kokrobitey, Kasoa and Nyanyano. South eastern Kasoa and south western Amasaman, however, have low seismic intensities (3.6 to 5.97).

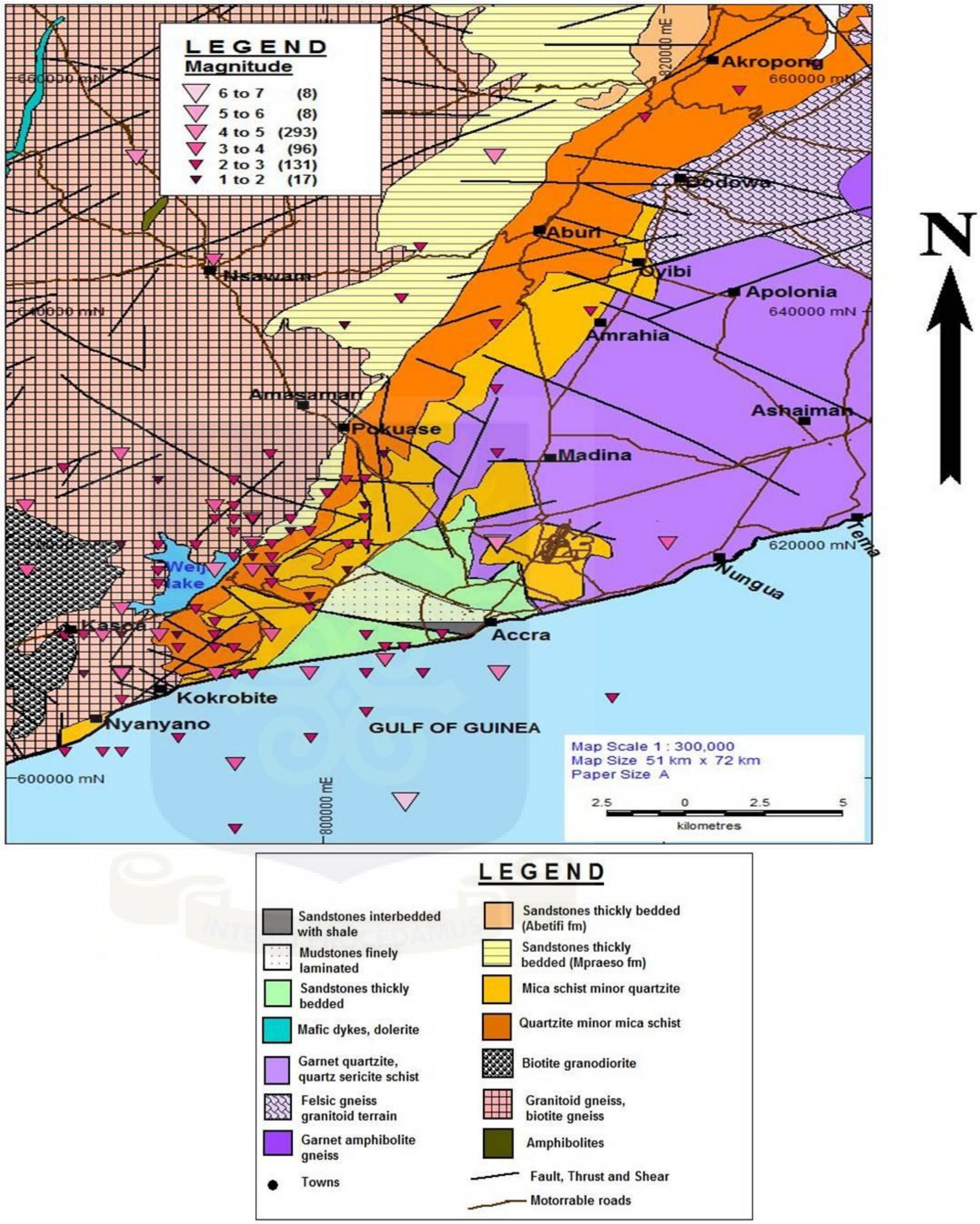

Fig. 5.1: Seismicity map of the study area

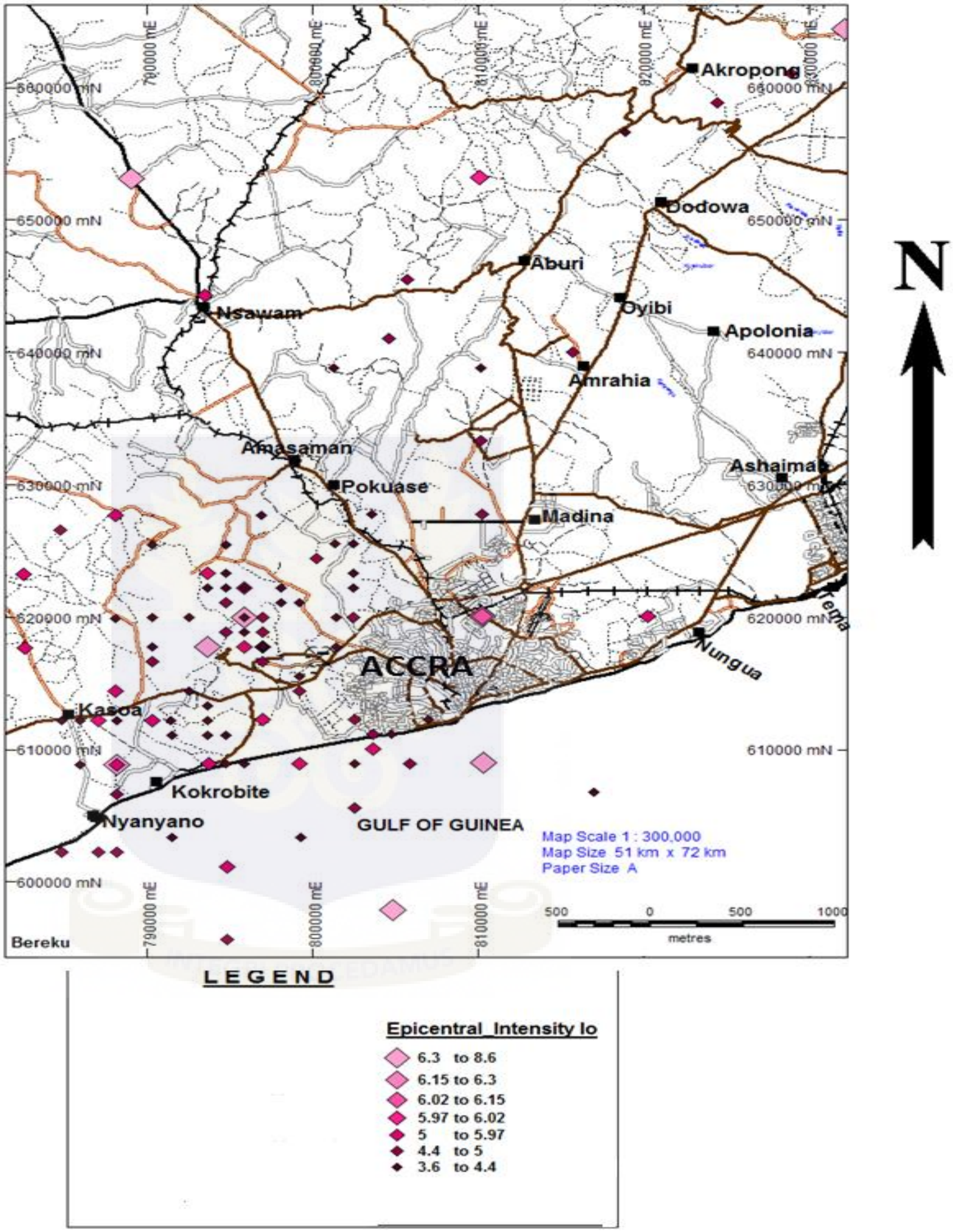

Fig. 5.2: A Plot of the Epicentral Intensity Map of the Study Area

5.1.3 b-VALUE EVALUATION

5.1.3.1 Linear Least Square Fit

A cumulative frequency table of events and their corresponding number of occurrence is shown in Table 5.2. This is the linear least square fit approach.

Table 5.2: Magnitudes and Cumulative Number of Events

M	N≥ M	Log(N≥ M)
2	553	2.742725131
2.5	447	2.650307523
3	405	2.607455023
3.5	381	2.580924976
4	311	2.492760389
4.5	47	1.672097858
5	16	1.204119983
5.5	11	1.041392685
6	8	0.903089987
6.5	3	0.477121255

The plot of graph showing the relationship between Log (N≥ M) and M is shown in Figure 5.3.

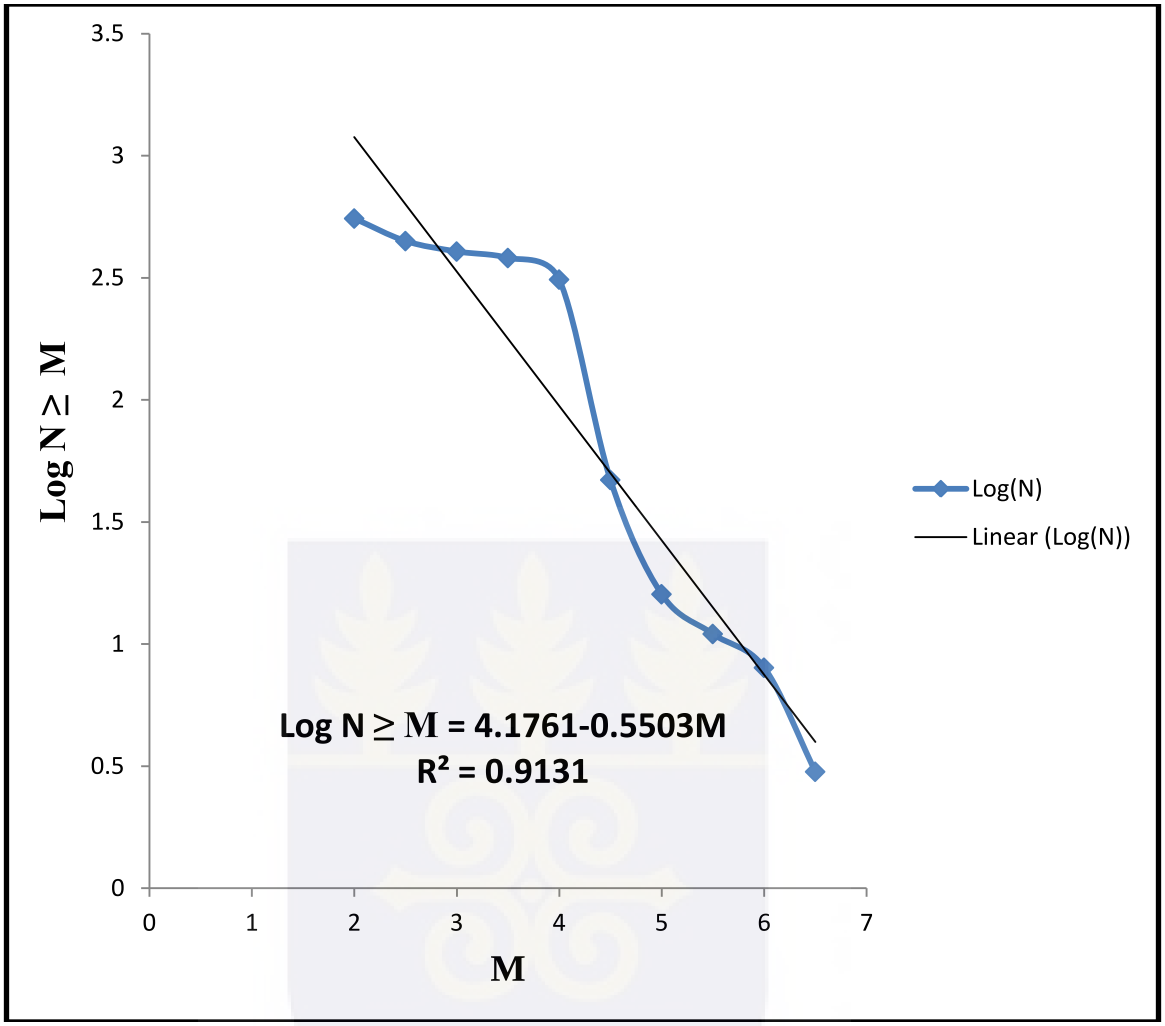

Fig. 5.3: Graph Indicating the Plot of Cumulative Number of Events against Magnitude

The b-value has been evaluated from the graph Fig 5.3 employing the equation below:

$$\text{Log } (N \geq M) = a - bM \qquad \text{……………………………………………………5.1}$$

where,

N is no. of events with magnitude ≥ M,

M is the magnitude of the events,

a and b are contants, thus a describes the seismic activity (log number of events with M = 0). It is determined by the event rate and for certain region depends upon the volume and time window considered.

Thus comparing equation 5.1 and Figure 5.3, the b-value was computed as 0.6. The Regression coefficient, R^2, is 0.9131. Thus, the variation in the regression is 91.31% explained by the independent variable M, the magnitude of events.

5.1.3.2 Maximum Likelihood Estimation

The maximum likelihood estimation method was used to evaluate the b-value according to Aki (1965), Marzorcchi and Sandri (2003), Lombardi (2003) and Felzer (2006)

$$b = 1/\left[\ln 10\,(m_{av} - m_c)\right] \qquad \text{……………………………………………………5.2}$$

where,

b represents the b-value

m_{av} represents the average magnitude from the catalogue and

m_c represents the threshold or cut off magnitude (usually carefully selected from the sharp curve exhibited by chart). The completeness of the earthquake catalogue, i.e. the estimation of the so-called threshold magnitude m_c is critical. In general, m_c magnitude of data set is obtained from the Guttenberg-Richter relation plot (plotting Log_{10} N (≥ M) against the magnitudes, M). m_c is the level at which the data falls below the line of best fit.

From Fig. 5.3 the threshold magnitude also known as the cut off magnitude, $m_{c,}$ was evaluated as 4.5. The average magnitude was subsequently calculated from the catalogue after applying the cut off magnitude. In calculating the average magnitude, m_{av}, forty seven (47) events were used. These include magnitudes 4.5 to 6.6. An average magnitude of 5.0 was obtained.

The b-value was then calculated using equation 5.2 as

$$b = 1/\,[\ln 10\ (5.0-4.5)] = 0.864 \approx 0.9,$$

The uncertainty associated with the analysis of the data was also calculated using the equation below:

$$\sigma_b = b/\sqrt{N} \qquad \text{......5.3}$$

where;

σ_b represents the uncertainty,

b represents the b-value and

N represents the number of earthquakes under consideration

$$\sigma_b = 0.864/\sqrt{47} = 0.126$$

5.1.4 RELATIONSHIP BETWEEN EARTHQUAKE EFFECTS AND GEOLOGY

To clearly understand the relationship between the geology of the study area and the seismicity, the epicentral intensity map was superimposed on the geology map of the study area as shown in Figure 5.4.

From the figure the south western GAMA is very active and therefore recorded a lot of the events captured in the study area. Areas such as Nyanyano, Kokrobite, Pokuase, Weija, Atomic, Kwabenya, Legon and the city centre Accra fall in this seismically active zone. There are some events however offshore. The area is mostly covered with sandstones which have been metamorphosed into quartzites. This process is usually related to tectonic compression within orogenic belts. It is therefore not strange to see most seismic events in the study area occurring here. These are also significant events considering that they have epicentral intensities as high as 8.6.

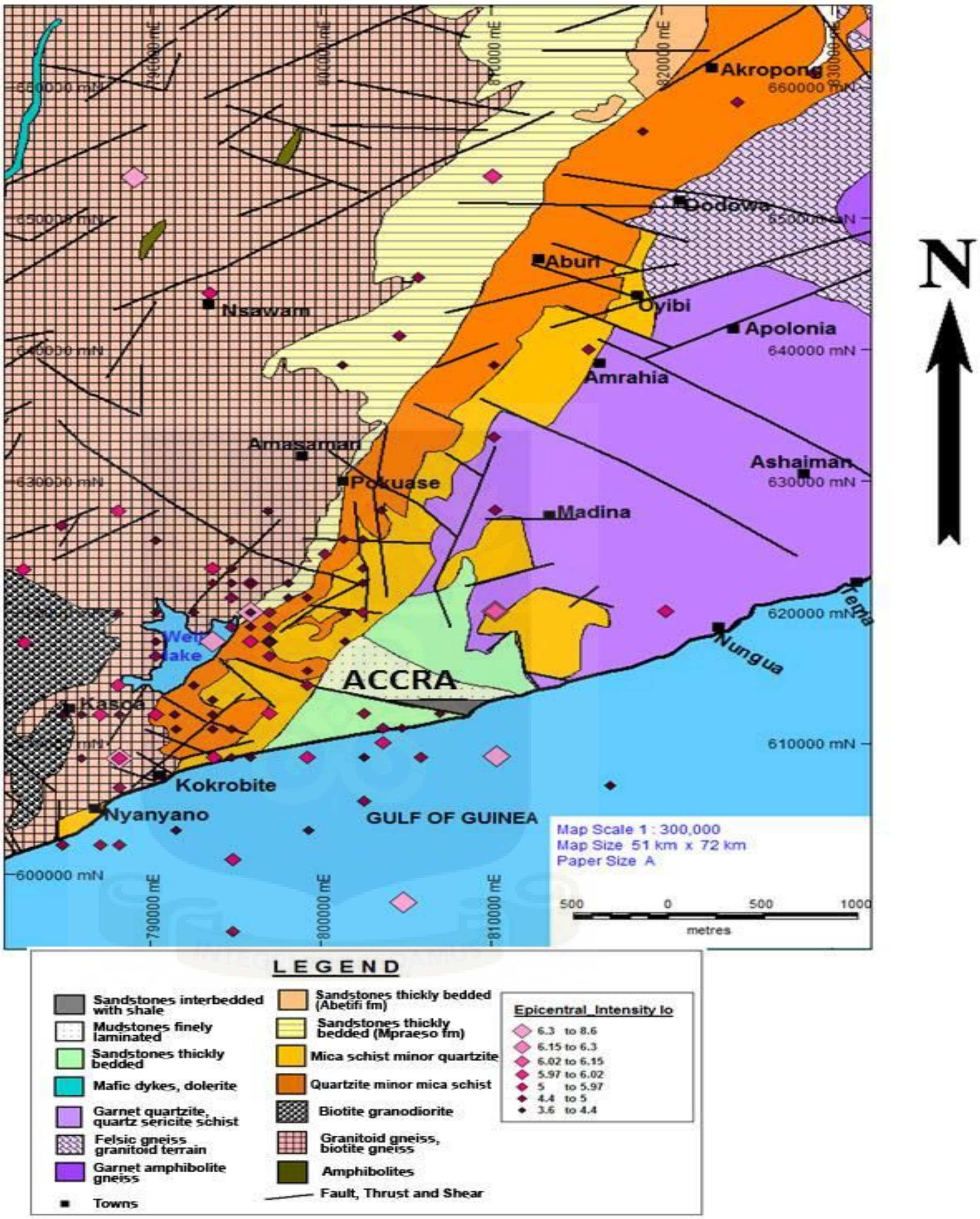

Fig. 5.4: Epicentral Intensity Superimposed on the Geology of Location

5.2 DISCUSSION

The research work was aimed at investigating earthquake hazard in the Greater Accra Metropolitan Area both by seismological and geological means. The seismological method involved establishing a comprehensive earthquake catalogue in order to study the history of earthquakes and earth tremors in the study area. The catalogue is an update of the one produced by Amponsah *et al*. (2012) which involved the relocation of some epicenters to reflect the current situation. There was also the interpolation of earthquake magnitude for events without magnitudes (resulting in magnitudes between 2.9 M_w and 6.6 M_w). A completely homogenized earthquake catalogue was generated with most seismic events occurring in and around Western Accra.

The seismicity map and epicentral intensity map generated from the catalogue clearly shows the earthquake prone zones in the metropolis is mostly around Western Accra, Nyanyano, Kasoa, Weija, Amasaman and Pokuase. It is also evident that major events are occurring off the coast of Ghana (GAMA). This can be associated with the well-defined unconsolidated and poorly consolidated sediments and soils which are prone to liquefaction and the formation of sand vents and mud volcanoes as described by Muff and Efa (2006). Events here can also be attributed to faults along the coast, some of which cause major displacements (Muff and Efa, 2006). The fact that these events have not been felt on-shore maybe indicative of silent and/or slow earthquakes (Singh *et al*., 2009). These events may be as a result of the Coastal boundary faults as observed by Sykes (1978) that the Cameroon line and the Ngaourandéré fault zone are situated near the boundary between the Congo and a belt of Pan-African deformation that extends as far as West of Accra, Ghana and captured in the fault map of GAMA as modified from Muff and Efa (2006) (Ennison *et al.*, 2012).

To investigate the earthquake hazard in the Greater Accra Metropolitan Area, one key objective was to calculate the b-value of GAMA from the earthquake catalogue that was compiled. The linear least square fit method resulted in a b-value of 0.6 and the maximum likelihood estimation of 0.9 approximately. The linear least square is disproportionately influenced by the largest earthquakes whilst the maximum likelihood estimation method weighs each earthquake equally. In fact, a b-value approximately 1 is indicative of the fact that there are relatively smaller shocks to larger ones in an earthquake catalogue. The b-value of 0.9, just like the earlier one (0.6) is in line with the globally accepted b-value of approximately 1.0 (Chen *et al.*, 2003; Lombardi, 2003; Marzocchi and Sandri, 2003; Felzer, 2006; Kulhanek, 2005). According to Talwani (1998), earthquake generation is influenced by several factors including the nature of the fault zone and the stress conditions. The b-value obtained confirms the relative abundance of large shocks to smaller shocks and is representative of stress and/or material conditions in the study area (Kulhanek, 2005). The uncertainty calculated from the maximum likelihood estimation of the b-value was 0.126 as compared to the coefficient of determination of 0.9131 obtained from the linear least square fit. The errors 0.126 and 0.0869 respectively may be due to the incompleteness of the catalogue or variations in scaling of magnitudes. The delimitation of the study area has lead to the generation of enough data for the seismic stress evaluation (b-value calculation). The 554 events used in this research would have been unattainable. The two methods used to evaluate the b-value were to test whether the best approach in terms of calculating the b-value. True to some schools of thought enumerated earlier the maximum likelihood estimation method gave am improved b-value of 0.9.

The superimposition of the epicentral intensities on the geology map (Figure 5.4) further confirms the earlier works pointing out seismic activity in the study area (Junner, 1941; Amponsah, 2002; Amponsah, 2004; Muff and Efa, 2006; Amponsah, *et al.*, 2009; Allotey *et al.*, 2010). The thematic maps (Figures 5.1, 5.2 and 5.4) further reveal the accumulation of events around the Weija Lake and the numerous faults, thrusts and shear zones around its vicinity. South western GAMA is very active and, therefore has recorded a lot of the events captured in the study area. These areas include Nyanyano, Kokrobite, Pokuase, Weija, Atomic, Kwabenya, Legon and the city centre Accra. Some events are also recorded offshore. They are also significant events (they have epicentral intensities as high as 8.6 and magnitudes to the tune of 6.6 M_w). The coast of Accra records events of epicentral intensities as high as 6.02 to 6.15 of magnitudes ranging between 4.02 and 4.15 whereas the offshore has epicentral intensities ranging from 3.6 to 8.6. It can be seen that all units of the Accraian sandstones have major faulting and jointing and are prone to earthquakes. Seismological activity is greatest in the unconsolidated sand and clay deposits around Sakumono, Densu Delta and South of Weija, Nyanyano, along the Togo Series alluvium boundary and in the area underlain by the Accraian rocks (Figure 5.3).

The faults, thrusts and shear zones (also confirmed by Junner, 1941; Amponsah, 2002; Amponsah, 2004; Amponsah, *et al.*, 2009; Allotey *et al.*, 2010; Muff and Efa, 2006 and Ennison *et al.*, 2012) cannot be left out when discussing the possible contributions to seismic activity in the study area. The blend of seismological and geological observations (the completely homogenized earthquake catalogue, the b-value calculated and the epicentral intensity map generated) from the investigations agrees to the observation that key areas of the Greater Accra Metropolitan Area are earthquake prone.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.0 CONCLUSION

After the compilation of an earthquake catalogue for Ghana and its immediate neighbours spanning the period 1615 to 2012, the seismicity map and the epicentral intensity map generated are just supplementary. After the superimposition of the epicentral intensity map on the geology map, the relationship between the seismic events and the geology has been established. The epicentral intensity map developed from the comprehensively harmonized earthquake catalogue generated has brought out the earthquake prone areas in the Greater Accra Metropolitan Area. Some of these areas are Weija, Kasoa, Nyanyano, Kokrobite, Southern Pokuase, Accra and offshore Accra. Nsawam, Madina Nungua, Tema, Ashaiman, Amrahia, Oyibi, Dodowa, Aburi and Apolonia on the other hand have not recorded very significant number of events. These areas may be said to be seismically stable. Further studies may be required to confirm this assertion though. Policy makers have no option but to rely on credible information on the seismicity (Earthquake catalogue, b-value calculated, seismicity map and the epicentral intensity map developed) of GAMA and update existing building codes and lay down clear guidelines for settlement.

The calculated b-value (0.6 and 0.9), indicative of the prevalence of small shocks over large ones, must be taken into consideration in order to locate more settlements at stress/fault free areas such as those mentioned earlier.

6.1 RECOMMENDATIONS

Based on the research work carried out it is recommended that

1. The earthquake catalogue compiled be relied upon to generate hazard maps
2. The seismicity map and the epicentral intensity map should serve as a guideline in updating building codes
3. Future b-value evaluations must be done to further explain the stress conditions in the metropolis
4. Further research must be carried out to assess the roles played by faults in concentrating stress and generating earthquakes since the major thrust of worldwide paleoseismological investigations has been to understand the temporal and spatial behaviour of seismically active faults (Rajendran, 2000).

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APPENDICES

APPENDIX A

DEFINITION OF KEY TERMS

The various terms that will reoccur in this research work are defined below

(a) Earthquakes

Earthquakes are the sudden release of strain energy accumulated in the rocks over extensive periods of time in the upper part of the Earth. Earthquakes are classified as, Slight ($M<5.0$), Moderate ($5.0<M<6.9$) and Great ($M>7.0$) depending upon the magnitude on Richter's scale. An earthquake having a magnitude, $M<2.0$ is termed as microearthquake. Here M represents magnitude. Generally, the word earthquake is used to describe any seismic event (whether natural or caused by humans) that generates seismic waves. Earthquakes are caused mostly by rupture of geological faults, but also by other events such as volcanic activity, landslides, mine blasts, and nuclear tests. Earthquakes' point of initial rupture is called its focus or hypocenter whilst the epicenter is the point at ground level directly above the hypocenter.

An earthquake can be a Foreshock or an Aftershock depending on whether it occurs before or after the Main shock respectively. Tectonic plates have internal stress fields caused by their interactions with neighbouring plates and sedimentary loading or unloading such as deglaciation. These stresses may be sufficient to cause failure along existing fault planes, giving rise to intraplate earthquakes. Earthquakes are estimated with magnitude and intensity measurements.

Some earthquakes are directly associated with forces acting along the plate boundaries and are called Inter-plate earthquakes. About 80% of the seismic energy is released by inter-plate earthquakes. In contrast, earthquakes which occur at rather large distances from the respective plate margins are called Intraplate earthquakes. They can be large and because of their unexpectedness and infrequency can result in severe damage. Earthquakes evidently cascade into aftershocks that readjust the hierarchical system of blocks-and-faults in the locality of the main shock rupture.

Lines connecting points on the earth's surface along which the intensity due to an earthquake is the same are referred to as Isoseismals. Isoseismals are usually a closed curve around the epicenter.

(b) Magnitudes

A measure of earthquake strength based upon the amount of ground motion experienced and corrected for the distance between the observation point and the epicenter (A point on the surface of the Earth, vertically above the place of origin (Hypocenter or Focus) of an earthquake). The measure of the strength of earthquakes or strain energy released is usually determined by seismographic observations. Originally, a simple pendulum and a needle suspended above a smoked glass plate allowed to distinguish primary and secondary earthquake waves and an accurate statement about location of the earthquake is established based on their timing.

In the early twentieth century the Russian Prince Boris Golitzyn invented analogue seismographs (magnitude measuring instrument). Present seismographs are digital instruments (Kossobokov, 2005).

Magnitude Scales

Depending on the range of magnitude, epicentral distance and the type of seismic waves considered in the computation, there are several magnitude scales in use. The most common ones are

- The Local Magnitude, M_L
- The Body-wave Magnitude, M_b
- The Surface-wave Magnitude, M_s
- Moment Magnitude, M_w

The first three magnitude scales depend on amplitude and time periods of seismic waves and suffer from saturation effect at higher magnitudes. Applicability uniformly to all magnitude ranges, epicentral distance and focal depths are other limitations the local magnitude, body-wave magnitude and the surface-wave magnitude suffer (Kanamori, 1982). The moment magnitude scale was introduced to help solve these problems. It is based on seismic moment, M_o which can help standardize all magnitudes and harmonize earthquake catalogues. The moment magnitude is defined as

$$M_w = (2/3)\log_{10}M_o - 10.7$$

M_o is the seismic moment defined by

$$M_o = \mu A d$$

where;

μ is the shear strength of the faulted block

A is the area of the fault and

D is the average displacement on the fault

These parameters are determined from wave form analysis of the seismograms produced by an earthquake. Seismic moment is measured in dyne-cm.

Another parameter commonly mentioned during hazard assessment is the intensity.

(c) Intensity

The subjective measure of the effects of an earthquake at a particular place on humans, structures or the land itself is referred to as intensity. Currently the Modified Mercalli Scale is used to measure earthquake intensity. The table below compares the intensity of earthquakes and their corresponding magnitudes.

Relationship Between Intensity and Magnitude of Earthquakes

Intensity	Verbal Description	Magnitude	Witness Observations
I	Instrumental	1 to 2	Detected only by seismographs
II	Feeble	2 to 3	Noticed only by sensitive people
III	Slight	3 to 4	Resembling vibrations caused by heavy traffic
IV	Moderate	4	Felt by people walking; rocking of free standing objects
V	Rather Strong	4 to 5	Sleepers awakened and bells ring
VI	Strong	5 to 6	Trees sway, some damage from overturning and falling object
VII	Very Strong	6	General alarm, cracking of walls
VIII	Destructive	6 to 7	Chimneys fall and there is some damage to buildings
IX	Ruinous	7	Ground begins to crack, houses begin to collapse and pipes break
X	Disastrous	7 to 8	Ground badly cracked and many buildings are destroyed. There are some landslides
XI	Very Disastrous	8	Few buildings remain standing; bridges and railways destroyed; water, gas, electricity and telephones out of action.
XII	Catastrophic	≥ 8	Total destruction; objects are thrown into the air, much heaving, shaking and distortion of the ground

(d) Disaster, Risk and Hazard

Disasters are natural or man-made (or technological) hazard resulting in significant physical damage or destruction, loss of life, or drastic change to the environment. Usually, areas prone to earthquakes, floods, catastrophic accidents, fires or explosions are declared disaster zones. In contemporary academia, the consequences of inappropriately managed risks are referred to as disasters.

Risks can mathematically be defined as

Risk = Hazard x Vulnerability – Capacity

Seismic hazards indicate the probable level of ground shaking occurring at a given point within a certain period of time. They quantify the ground motion required at a particular site (Gupta and Kijko, 2011).

Generally, society is faced with a continuum of risk ranging from everyday risks to natural disasters like earthquakes (Allotey et al, 2010).

(e) Epicenter

It is the point on the surface of the Earth, vertically above the place of origin (Hypocenter or Focus) of an earthquake. This point is expressed by its geographical coordinates in terms of latitude and longitude.

(f) Seismicity and Aseismicity

Seismicity refers to the frequency of earthquake activity in a given area. Global seismicity maps show that seismicity is the highest at the tectonic plates. Aseismicity on the other hand, refers to the absence of frequent earthquakes of significant magnitude.

(g) Probabilistic and Deterministic Seismic Hazard Assessment

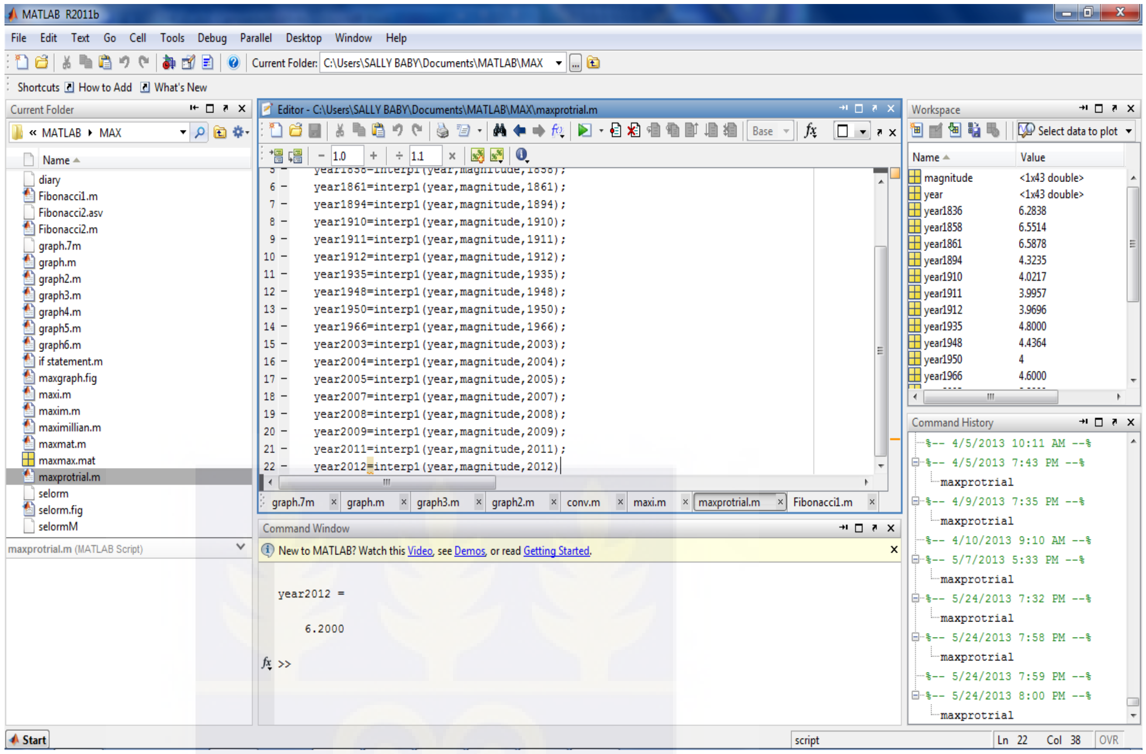
A hazard assessment method is said to be probabilistic if it evaluates the likelihood or frequency of a specified level of ground motion at a site during a specified exposure time. On the other hand deterministic seismic hazard assessments are used to evaluate a particular earthquake scenario.

APPENDIX B
MATLAB INTERPOLATION
(α) Command and Results

```
year=[1636 1788 1862 1870 1871 1872 1879 1883 1889 1906 1907 1930
1933 1939 1950 1964 1969 1973 1974 1977 1978 1979 1987 1988 1989
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002
2003 2009 2010 2011 2012];
magnitude=[5.8 5.7 6.6 4.6 4.7 5.0 5.8 4.7 4.0 5.1 4.1 3.5 4.0
6.4 4.0 4.4 4.9 2.4 3.6 2.8 3.7 3.4 2.7 3.3 2.1 3.3 3.7 2.0 4.2
2.8 3.8 3.4 4.6 2.3 2.6 3.1 2.2 3.0 2.9 4.4 4.6 4.6 6.2 ];
year1836=interp1(year,magnitude,1836);
year1858=interp1(year,magnitude,1858);
year1861=interp1(year,magnitude,1861);
year1894=interp1(year,magnitude,1894);
year1910=interp1(year,magnitude,1910);
year1911=interp1(year,magnitude,1911);
year1912=interp1(year,magnitude,1912);
year1935=interp1(year,magnitude,1935);
year1948=interp1(year,magnitude,1948);
year1950=interp1(year,magnitude,1950);
year1966=interp1(year,magnitude,1966);
year2003=interp1(year,magnitude,2003);
year2004=interp1(year,magnitude,2004);
year2005=interp1(year,magnitude,2005);
year2007=interp1(year,magnitude,2007);
year2008=interp1(year,magnitude,2008);
year2009=interp1(year,magnitude,2009);
year2011=interp1(year,magnitude,2011);
year2012=interp1(year,magnitude,2012)
```

magnitude	<1x43 double>
year	<1x43 double>
year1836	6.283783783783783
year1858	6.551351351351351
year1861	6.587837837837838
year1894	4.323529411764706
year1910	4.021739130434782
year1911	3.995652173913043
year1912	3.969565217391304
year1935	4.800000000000000
year1948	4.436363636363637
year1950	4
year1966	4.600000000000001
year2003	2.900000000000000
year2004	3.150000000000000
year2005	3.400000000000000
year2007	3.900000000000000
year2008	4.150000000000000
year2009	4.400000000000000
year2011	4.600000000000000
year2012	6.200000000000000

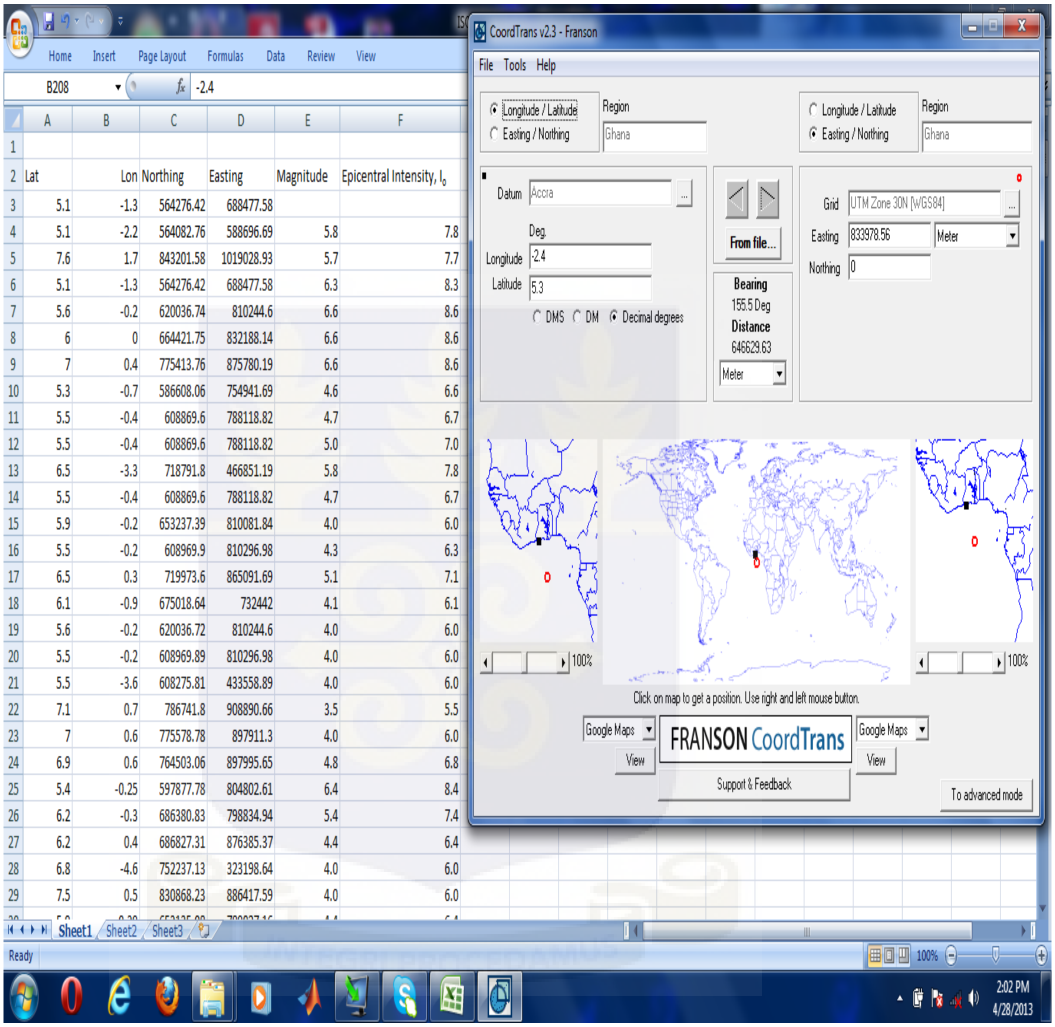
(β) Matlab Window



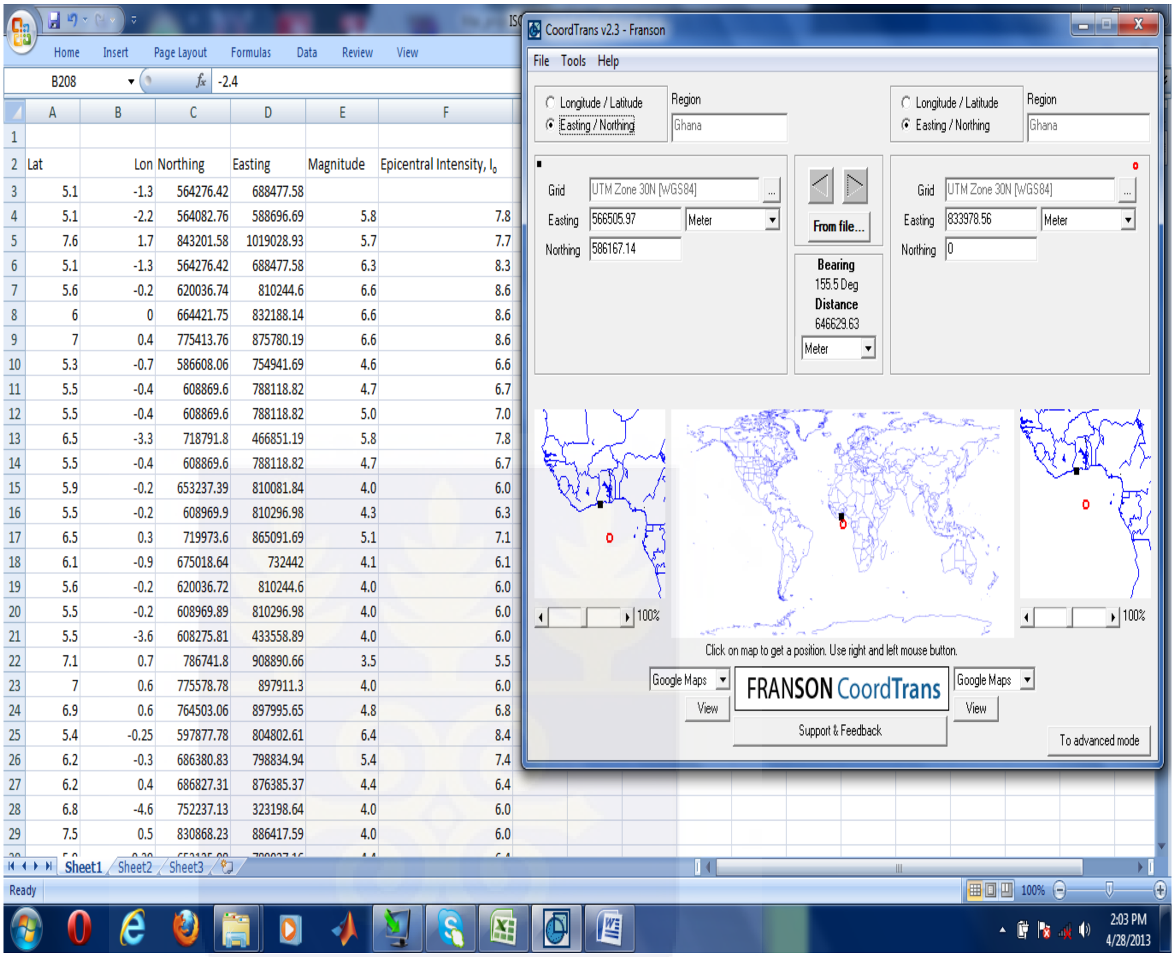
APPENDIX C

LATITUDE/LONGITUDE CONVERSION TO METRES

(a) Window 1



(b) Window 2


Home
Insert
Page Layout
Formulas
Data
Review
View
B208
-2.4
Lat
Lon
Northing
Easting
Magnitude
Epicentral Intensity, I0
CoordTrans v2.3 - Franson
File
Tools
Help
Longitude / Latitude
Easting / Northing
Region
Ghana
Grid
UTM Zone 30N [WGS84]
Easting
566505.97
Meter
Northing
586167.14
From file...
Bearing
155.5 Deg
Distance
646629.63
833978.56
0
Click on map to get a position. Use right and left mouse button.
Google Maps
View
FRANSON CoordTrans
Support & Feedback
To advanced mode
Sheet1
Sheet2
Sheet3
Ready

(c) Epicentral Intensity Table

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
5.1	-1.3	564276.42	688477.58		
5.1	-2.2	564082.76	588696.69	5.8	7.8
7.6	1.7	843201.58	1019028.93	5.7	7.7
5.1	-1.3	564276.42	688477.58	6.3	8.3
5.6	-0.2	620036.74	810244.6	6.6	8.6
6	0	664421.75	832188.14	6.6	8.6
7	0.4	775413.76	875780.19	6.6	8.6
5.3	-0.7	586608.06	754941.69	4.6	6.6
5.5	-0.4	608869.6	788118.82	4.7	6.7
5.5	-0.4	608869.6	788118.82	5.0	7.0
6.5	-3.3	718791.8	466851.19	5.8	7.8
5.5	-0.4	608869.6	788118.82	4.7	6.7
5.9	-0.2	653237.39	810081.84	4.0	6.0
5.5	-0.2	608969.9	810296.98	4.3	6.3
6.5	0.3	719973.6	865091.69	5.1	7.1
6.1	-0.9	675018.64	732442	4.1	6.1
5.6	-0.2	620036.72	810244.6	4.0	6.0
5.5	-0.2	608969.89	810296.98	4.0	6.0
5.5	-3.6	608275.81	433558.89	4.0	6.0
7.1	0.7	786741.8	908890.66	3.5	5.5
7	0.6	775578.78	897911.3	4.0	6.0
6.9	0.6	764503.06	897995.65	4.8	6.8
5.4	-0.25	597877.78	804802.61	6.4	8.4

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
6.2	-0.3	686380.83	798834.94	5.4	7.4
6.2	0.4	686827.31	876385.37	4.4	6.4
6.8	-4.6	752237.13	323198.64	4.0	6.0
7.5	0.5	830868.23	886417.59	4.0	6.0
5.9	-0.39	653135.08	789027.16	4.4	6.4
5.58	-0.35	617746.34	793623.45	4.6	6.6
5.5	-0.2	608969.89	810296.98	4.9	6.9
5.7	0.3	631397.14	865634.66	2.4	4.4
7	0.8	775753.3	920047.16	1.9	3.9
5	-2.6	552987.57	544364.84	3.6	5.6
6.5	0.5	720122.64	887243.41	1.9	3.9
5	-2.6	552987.57	544364.84	3.1	5.1
5.8	0.8	642816.99	921031.82	2.6	4.6
5.1	2.5	566640.18	1110573.39	3.4	5.4
5.77	-0.2	638850.39	810153.41	2.0	4.0
6.02	-0.2	666517.72	810014.36	2.5	4.5
5.72	-0.2	633316.95	810180.51	2.7	4.7
5.58	-0.28	617781.75	801384.65	1.9	3.9
6.23	-0.13	689800.1	817646.11	2.1	4.1
5.95	-0.07	658845.62	824460.34	2.4	4.4
5.67	-0.2	627783.52	810207.38	2.5	4.5
5.63	0.02	623478.49	834623.62	2.1	4.1
5.65	-0.28	625528.03	801348.63	2.0	4.0
5.57	-0.38	616624.92	790302.27	2.4	4.4

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
5.97	-0.03	661083.03	828881.49	2.8	4.8
5.58	-0.38	617731.45	790297.35	2.2	4.2
6	0.12	664496.09	845487.5	2.0	4.0
6.58	0.13	728710.12	846210.99	2.8	4.8
5.53	-0.38	612198.84	790321.87	3.0	5.0
6.6	0.27	731023.85	861697.12	2.0	4.0
5.63	-0.35	623279.08	793598.42	3.7	5.7
5.63	-0.35	623279.08	793598.42	2.1	4.1
5.53	-0.4	612189.09	788104.33	1.9	3.9
5.53	-0.37	612203.74	791430.65	1.9	3.9
5.58	-0.32	617761.4	796949.62	3.4	5.4
5.5	-0.33	608903.84	795880.77	2.2	4.2
5.57	-0.38	616624.92	790302.27	2.2	4.2
5.52	-0.35	611107.05	793653.18	2.3	4.3
5.5	-0.42	608859.97	785901.2	1.9	3.9
5.53	-0.43	612174.62	784778.08	2.1	4.1
5.77	-0.28	638807.39	801285.83	1.9	3.9
5.44	-0.4	602230.58	788147.57	2.7	4.7
5.67	-0.26	627751.7	803555.48	1.9	3.9
5.58	-0.32	617761.4	796949.62	2.5	4.5
5.51	-0.26	610045.64	803638.06	3.0	5.0
5.53	-0.41	612184.25	786995.57	3.0	5.0
5.5	-0.4	608869.59	788118.82	3.2	5.2
5.63	-0.27	623319.98	802467.65	1.9	3.9

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
5.56	-0.3	615558.35	799177.26	1.9	3.9
5.6	-0.28	619994.97	801374.41	2.0	4.0
5.6	-0.11	620085.14	820224.28	3.3	5.3
5.61	-0.31	621086.21	798043.15	1.9	3.9
5.6	-0.32	619974.55	796939.53	2.1	4.1
5.45	-0.37	603351.52	791469.58	2.3	4.3
5.48	-0.4	606656.59	788128.44	2.4	4.4
5.59	-0.33	618862.92	795835.87	1.9	3.9
5.31	-0.6	587756.43	766027.17	2.1	4.1
5.61	-0.34	621071.01	794717.12	2.6	4.6
5.59	-0.34	618857.89	794727.16	2.9	4.9
5.4	-0.55	597735.52	771532.48	3.3	5.3
5.44	-0.41	602225.82	787038.65	2.6	4.6
5.93	-0.12	656602.92	818930.74	2.3	4.3
5.61	-0.3	621091.31	799151.85	2.1	4.1
5.62	-0.31	622192.79	798038.06	2.3	4.3
5.64	-0.29	624416.24	800245.14	2.9	4.9
5.62	-0.35	622172.53	793603.45	2.3	4.3
5.62	-0.33	622182.62	795820.74	3.7	5.7
5.53	-0.35	612213.6	793648.25	2.3	4.3
5.62	-0.33	622182.62	795820.74	2.0	4.0
5.5	-0.27	608933.93	802534.21	2.1	4.1
1.3	1.62	144480.68	1014557.07	4.2	6.2
5.53	-0.23	612274.32	806954.57	2.3	4.3

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
5.63	-0.56	623177.51	770319.35	2.3	4.3
5.53	-0.27	612253.78	802518.99	2.7	4.7
5.59	-0.32	618867.97	796944.58	2.4	4.4
4.05	-2.44	447987.85	562183.67	2.7	4.7
5.52	-0.34	611112	794762.01	2.1	4.1
5.55	-0.36	614421.73	792529.59	2.3	4.3
5.5	-0.34	608898.89	794771.89	2.1	4.1
5.38	-0.34	595620.26	794830.41	2.5	4.5
5.47	0.55	606090.07	893520.29	2.3	4.3
5.6	-0.27	620000.12	802483.15	2.4	4.4
5.47	-0.27	605614.08	802549.35	2.0	4.0
5.36	-0.32	593416.83	797058.31	1.9	3.9
5.52	-0.37	611097.21	791435.55	2.3	4.3
7.65	-3.48	845937.29	447079.85	2.8	4.8
5.53	-0.42	612179.42	785886.82	2.0	4.0
5.6	-0.4	619934.62	788070.2	1.9	3.9
5.54	-0.35	613320.14	793643.31	2.3	4.3
5.52	-0.25	611157.38	804741.88	2.0	4.0
5.45	-0.3	603385.85	799232.35	2.2	4.2
5.6	-0.28	619994.96	801374.41	2.3	4.3
5.6	-0.36	619954.43	792504.79	2.3	4.3
5.53	-0.32	612228.53	796974.71	3.1	5.1
5.55	-0.4	614402.1	788094.62	3.2	5.2
5.63	-0.57	623172.89	769210.91	2.5	4.5

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
5.63	-0.45	623229.66	782512.68	3.6	5.6
5.6	-0.32	619974.54	796939.53	2.6	4.6
5.58	-0.33	617756.35	795840.89	3.2	5.2
5.55	-0.3	614451.75	799182.31	2.5	4.5
5.52	-0.26	611152.26	803632.97	2.4	4.4
5.5	-0.24	608949.23	805861.05	2.5	4.5
5.5	-0.35	608893.96	793663.02	3.8	5.8
5.57	0.06	616859.98	839094.24	2.2	4.2
5.58	-0.45	617697.35	782536.76	3.4	5.4
5.28	-1.42	584146.57	675121.64	2.8	4.8
5.43	-0.34	601153.02	794806.18	3.0	5.0
5.44	-0.48	602192.96	779276.41	2.4	4.4
5.44	-0.47	602197.6	780385.28	2.3	4.3
5.52	-0.49	611039.73	778130.48	2.4	4.4
5.44	-0.43	602216.33	784820.82	2.9	4.9
5.62	-0.27	622213.35	802472.83	2.3	4.3
5.47	-0.27	605614.08	802549.35	2.4	4.4
5.67	-0.32	627720.57	796903.91	2.2	4.2
5.82	-0.35	644303.56	793501.3	3.2	5.2
5.63	-0.34	623284.12	794707.04	2.1	4.1
5.66	-0.43	626558.83	784715.1	2.6	4.6
5.67	-0.4	627680.15	788035.65	3.9	5.9
5.6	-0.33	619969.48	795830.83	4.6	6.6
5.6	-0.38	619944.48	790287.48	2.2	4.2

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
5.65	-0.38	625477.09	790262.65	1.9	3.9
5.65	-0.34	625497.23	794696.93	2.2	4.2
5.62	-0.34	622177.56	794712.09	2.0	4.0
5.62	-0.34	622177.56	794712.09	2.3	4.3
5.6	-0.33	619969.48	795830.83	2.3	4.3
5.75	0.01	636755.43	833445.37	2.0	4.0
5.72	0.28	633598.8	863403.79	2.0	4.0
5.77	0.18	639071.73	852282.85	2.3	4.3
5.25	-0.22	581293.02	808204.91	2.0	4.0
5.35	0	592474.54	832561.18	2.2	4.2
5.79	-0.25	641036.65	804600.39	2.5	4.5
6.1	-1.29	674865.95	689264.14	2.6	4.6
5.79	0.29	641355.45	864468.17	2.4	4.4
5.3	-0.32	586777.42	797087.19	2.3	4.3
6.59	0.48	730074.11	884958.91	2.1	4.1
5.32	-0.01	589148.54	831467.85	2.3	4.3
5.48	-0.14	606787.95	816961.72	2.1	4.1
5.78	-0.15	639984.63	815690.4	2.5	4.5
5.59	-0.86	618622.43	737085.84	2.2	4.2
5.66	2.6	628930.8	1121137.05	2.6	4.6
5.54	0.13	613579.71	846875.93	3.1	5.1
5.83	-0.24	645468.65	805687.18	2.7	4.7
5.56	0.18	615823.37	852410.42	2.2	4.2
5.75	0.85	637315.22	926617.14	2.6	4.6

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
5.6	0.13	620221.77	846840.66	2.7	4.7
5.4	-0.5	597758.08	777076.97	2.8	4.8
5.6	0.1	620204.09	843513.29	2.2	4.2
5.65	-0.27	625533.21	802457.27	2.3	4.3
5.5	-0.3	608918.8	799207.45	3.0	5.0
5.55	0.5	614916.8	887919.12	2.0	4.0
5.25	-0.6	581118.45	766052.79	2.0	4.0
5.57	-0.32	616654.82	796954.66	2.9	4.9
5.58	-0.32	617761.39	796949.62	2.2	4.2
5.57	-0.38	616624.92	790302.27	2.6	4.6
6.7	-1.9	741026.58	621604.08	2.9	4.9
5.3	-2.6	586149.27	544344.04	3.2	5.2
7.4	-7.1	820361.41	47181.05	3.2	5.2
3.7	-6.3	409962.47	133361.63	3.4	5.4
5.7	-6.9	631813.31	67839.63	3.9	5.9
4.6	-3.9	508822.9	400187.67	4.2	6.2
6.2	-4.7	685921.24	311921.1	4.2	6.2
9.2	-1.5	1017607.06	664822.94	4.2	6.2
6.7	2.2	743944.79	1075515.02	4.4	6.4
9.4	-2.4	1039429.59	565898.62	4.4	6.4
7	-1.9	774195.49	621528.09	4.4	6.4
7.3	-2.1	807315.82	599369.14	1.9	3.9
11.8	0.1	1306599.81	837891.17	2.4	4.4
6.4	-6.2	708831.29	145956.02	4.1	6.1

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
5.4	-3.1	597189.59	488942.79	2.7	4.7
5.6	-5.8	620036.71	189798.46	4.0	6.0
6.7	-4.9	741296.92	289990.25	4.1	6.1
11.8	1	1307846.27	936112.99	4.2	6.2
10.7	0	1184699.36	828228.22	3.9	5.9
7.1	-6.1	786254.19	157524.83	4.2	6.2
1.1	-3.1	121902.75	488895.73	4.3	6.3
6.7	-4.5	741143.71	334218.57	4.0	6.0
-7.5	-13.3	-842195.43	-642412.23	4.6	6.6
8.7	-4.6	962356.93	323990.35	4.1	6.1
11.8	3.1	1311997.57	1165723.46	4.3	6.3
7.3	-4.3	807423.6	356513.19	4.4	6.4
6.8	-7.6	754368.04	-8814.78	3.9	5.9
6.2	-6	686559.56	167978.27	2.8	4.8
5.3	-2.4	586167.14	566505.97	3.8	5.8
12	0.9	1329854.2	924883.33	4.1	6.1
6.7	-4.4	741111.04	345274.34	4.1	6.1
5.8	-4.9	641756.66	289630.6	4.3	6.3
7.3	-6.1	808394.72	157675.17	4.2	6.2
14.2	0.3	1572648.17	856262.72	4.3	6.3
12.7	1	1407588.2	934632.79	4.1	6.1
7.8	-5.6	863373.63	213263.07	4.1	6.1
13.6	0.5	1506498.15	878852.98	2.3	4.3
12.7	0.4	1406660.08	869365.29	4.0	6.0

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
7.7	-3.9	851539.6	400764.64	3.8	5.8
6.7	-4.4	741111.04	345274.34	3.9	5.9
6.5	-5.3	719360.39	245649.7	4.1	6.1
6.5	-5.1	719264.11	267779.18	4.2	6.2
10.6	-3.1	1172047.81	489082.42	3.8	5.8
6.7	-4.8	741255.23	301048.19	4.2	6.2
-4.8	-11.8	-536554.82	-479652.5	4.3	6.3
5.8	-5.1	641834.88	267474.87	4.6	6.6
1.7	-3.2	188220.75	477775.56	4.3	6.3
12.2	12.2	1396653.91	2171532.15	4.0	6.0
5.7	-4.4	630538.26	344982.36	4.1	6.1
10.1	-2.8	1116771.26	521934.46	4.1	6.1
-1.2	-18	-137011.07	-1188300.98	4.3	6.3
-0.5	-5.4	-54990.68	232884.56	4.2	6.2
-8.4	-5.2	-928862.12	257758.54	4.3	6.3
3.7	-5.4	409640.72	233429.17	4.4	6.4
12.2	-1.1	1349683.61	706739.42	4.2	6.2
5.8	-6	642284	167735.61	4.1	6.1
11.8	2	1309605.15	1045366.08	4.2	6.2
-5.5	-4.5	-607810.12	333847.57	4.3	6.3
6.2	-6.1	686623.34	156899.71	4.0	6.0
6.1	-6	675490.62	167916.1	3.9	5.9
6.6	-4.8	730195.66	301007.92	4.1	6.1
5.3	-4.7	586393.33	311625.01	4.3	6.3

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
6.7	-4.8	741255.23	301048.19	4.3	6.3
8	-4.5	884900.83	334700.33	4.1	6.1
6.7	-2.2	740962.4	588442.69	2.2	4.2
5.3	-4.7	586393.33	311625.01	4.2	6.2
1.4	0.3	155320.23	867335.38	4.2	6.2
6.4	-4.6	708003.41	323056.57	4.0	6.0
4.9	-1.6	542082.61	655260.49	3.8	5.8
0	1.6	322.88	1012456.97	4.1	6.1
11.9	-4.4	1316170.56	347545.45	2.3	4.3
7.3	-3.6	807260.71	433791.27	3.7	5.7
12.5	1.2	1385761.06	956753.19	4.3	6.3
6.1	-6.1	675553.39	156835.45	3.3	5.3
7.4	-3.6	818315.84	433806.08	4.2	6.2
5.7	-5.8	631103.56	189851.78	3.7	5.7
6.7	-4.8	741255.23	301048.19	4.2	6.2
6.8	-6.3	753190.2	135173.27	4.0	6.0
5.8	-5.4	641966.92	234235.94	4.5	6.5
4.3	-5	475890.49	278042.82	4.2	6.2
6.2	-6.1	686623.34	156899.71	3.7	5.7
3	-3.3	331912.59	466683.37	4.4	6.4
5.9	-1.8	652600.83	632861.96	4.1	6.1
6.8	-4.7	752274.83	312144.13	4.2	6.2
-5.4	-10.9	-602268.45	-377962.53	4.1	6.1
-5.5	-11.1	-613728.19	-400184.69	4.3	6.3

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
5.3	-5	586492.61	278366.2	4.2	6.2
5.7	-5.9	631158.41	178765.1	4.5	6.5
-8.3	-2.6	-917149.63	544070.46	3.9	5.9
5.4	-5.3	597670.55	245142.82	4.3	6.3
8.1	-4.9	896143.83	290652.08	4.2	6.2
6.9	1.2	765047.41	964432.7	4.2	6.2
1.1	1.3	122248.92	978883.3	4.0	6.0
6.2	-5.7	686380.81	201208.13	3.9	5.9
3.7	-3.4	409289.98	455602.08	4.3	6.3
4.8	-5.4	531333.98	233807.41	4.2	6.2
6.8	-4.9	752357.14	290033.39	4.2	6.2
6	-3.3	663520.77	466819.67	4.3	6.3
6.2	-3.5	685645.74	444705.17	4.0	6.0
5.6	-4	619390.56	389265.58	3.9	5.9
12.7	-3.7	1404350.38	424019.04	3.7	5.7
12.6	0.9	1396341.6	923917.51	4.2	6.2
5.3	-4.2	586263.68	367045.44	4.4	6.4
5.3	-5.5	586693.95	222921.03	4.2	6.2
12.4	0.9	1374178.96	924244.6	4.5	6.5
3.2	-0.7	354300.94	755633.58	2.9	4.9
8.4	-6.4	930444.71	125497.39	2.0	4.0
8.4	-5.4	929628.67	235726.63	3.9	5.9
6.6	-4.9	730236.74	289947.74	3.8	5.8
6.4	-5.1	708202.68	267733.59	4.2	6.2

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
7.2	-3.1	796163.33	488980.91	4.2	6.2
8.6	-2.3	951000.11	577047.72	4.3	6.3
6.7	-4.8	741255.23	301048.19	4.0	6.0
11.9	0.2	1317795.92	848673.33	3.8	5.8
6.5	-4.6	719061.77	323091.28	4.0	6.0
7	-2.5	774082.65	555249.15	4.2	6.2
5.9	-5.9	653294.11	178878.48	4.1	6.1
10	0	1107205.25	828958.07	4.2	6.2
-9.5	-2.7	-1049808.33	532950.68	4.3	6.3
6.5	0.7	720280.5	909399.76	3.8	5.8
6.1	-6.2	675618.23	145753.77	4.4	6.4
4.1	-5	453770.38	277986.21	4.0	6.0
6.6	-4.6	730120.18	323126.53	4.4	6.4
6.3	-3.7	696725.65	422592.4	3.9	5.9
16.2	-6.3	1794173.98	147129.75	3.9	5.9
12.5	0.5	1384650.63	880536.11	4.0	6.0
6.7	-4.9	741296.92	289990.25	2.4	4.4
13	1.4	1441554.75	977598.83	4.1	6.1
7	-4.8	774434.18	301172.6	3.9	5.9
6	-5.2	664000.83	256483.38	4.3	6.3
5.3	-4.4	586310.17	344878.71	4.3	6.3
7.5	-5	829828.9	279313.77	4.0	6.0
5.4	-5.4	597713.4	234054.86	4.3	6.3
6.8	-5.5	752659.07	223685.09	4.3	6.3

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
10.3	-0.6	1139862.01	762884.53	2.2	4.2
6.7	-4.8	741255.24	301048.19	3.8	5.8
1.1	-5.9	122059.9	177234.7	3.9	5.9
6	-3.8	663576.33	411480.8	4.0	6.0
7.6	1.1	842525.81	952654.55	3.7	5.7
12.8	1.3	1419195.61	967098.41	4.2	6.2
5.9	-5.3	652983.63	245361.65	4.3	6.3
4.5	-1.3	497926.26	688642.45	4.4	6.4
4.8	-5.2	531259.34	256003.24	4.1	6.1
5.4	-5.4	597713.4	234054.86	4.0	6.0
6.6	-4.9	730236.75	289947.74	4.2	6.2
6.3	-4.6	696945.09	323022.39	4.1	6.1
6.2	-5.3	686171.86	245502.21	4.3	6.3
8	-3.7	884665.11	422878.31	4.2	6.2
6.6	-4.7	730156.81	312067.51	4.1	6.1
14.1	0.1	1561278.04	834799.71	4.0	6.0
6.6	-4.8	730195.67	301007.92	3.9	5.9
6.6	-6.2	730973.47	146096.22	4.4	6.4
5.6	-4.4	619481.19	344955.74	3.8	5.8
6.3	-5.2	697186.92	256620.02	4.3	6.3
6.8	-5	752401.73	278977.1	4.2	6.2
13.5	0.7	1495739.37	900694.64	3.8	5.8
9.4	-2.7	1039387.33	532959.64	4.4	6.4
5.4	-5.2	597629.54	256230.02	4.2	6.2

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
7.5	-2.2	829406.24	588289.99	2.4	4.4
8.6	-5.4	951757.66	235863.76	2.2	4.2
5.6	-2.8	619299.97	522171.65	4.4	6.4
5.3	-5	586492.62	278366.2	4.2	6.2
6.1	-4.9	674936.42	289744.75	4.1	6.1
6.5	-3.5	718809.27	444737.19	4.1	6.1
3	-5.6	332251.74	210992.8	4.6	6.6
-11.3	-10.3	-1258819.44	-298685.81	4.1	6.1
5.3	-4.5	586336.1	333794.65	4.4	6.4
10.1	-6.8	1119190.73	83388.05	3.8	5.8
8	-5.1	885190.27	268547.28	4.0	6.0
5.2	-5	575432.28	278330.84	4.3	6.3
6.6	-4.8	730195.67	301007.92	3.9	5.9
7	-5.7	774910.75	201688.19	3.8	5.8
5.3	-5.2	586567.77	256190.37	4.2	6.2
6	-4.5	663739	333994.3	4.1	6.1
7.1	-4.3	785309.1	356450.27	2.2	4.2
-1	-7.4	-110534.09	9985.08	4.1	6.1
5.4	-1.8	597319.79	632976.02	3.9	5.9
2.5	-5.7	276952.08	199742.9	4.3	6.3
7.7	-3.9	851539.6	400764.64	4.3	6.3
6.7	-4.8	741255.24	301048.19	4.3	6.3
5.7	-4.2	630488.31	367134.27	4.1	6.1
6.5	-4.8	719136.14	300968.26	3.3	5.3

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
4.2	-5	464830.42	278014.18	4.4	6.4
4.4	-4.3	486778.76	355771.26	4.1	6.1
6.1	-6.2	675618.23	145753.77	4.0	6.0
12.7	1.4	1408291.23	978168.19	4.3	6.3
6.3	-6.3	697829.31	134808.98	4.4	6.4
6.8	-6.2	753115.77	146240.71	4.2	6.2
-2.8	-7.8	-310252.76	-34109.4	4.0	6.0
5.9	-6.1	653413.59	156710.05	3.8	5.8
2.6	-3	287695.92	500021.53	4.2	6.2
5.6	-4	619390.57	389265.58	4.1	6.1
7.2	-3.6	796205.62	433776.65	4.6	6.6
10.8	-4.1	1194375.52	379763.32	3.9	5.9
11.7	2.7	1299963.88	1122158.82	4.5	6.5
12.2	1.7	1353403.25	1011816.83	4.3	6.3
5.3	-4.8	586424.64	300539.35	4.4	6.4
-0.8	-5.5	-88185.02	221763.25	4.3	6.3
6.1	-6.1	675553.4	156835.45	4.3	6.3
6.4	-3.5	707754.72	444726.35	4.3	6.3
6.1	-5.1	675018.63	267601.06	4.0	6.0
5.6	-4	619390.57	389265.58	4.1	6.1
4.1	-5.6	453961.91	211335.29	4.4	6.4
3.9	-3.3	431392.39	466714.74	3.7	5.7
-0.4	-8	-44058.11	-57069.75	4.2	6.2
6.5	-5.9	719701.92	179241.96	4.2	6.2

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
7.2	-4.5	796434.01	334393.84	4.3	6.3
6.2	-2.3	685670.78	577465.37	3.9	5.9
13.4	0.9	1484993.96	922557.68	4.0	6.0
12.7	-3.6	1404323.3	434876.93	3.9	5.9
8.8	-7.1	975514.31	48748.62	4.6	6.6
11.7	1.8	1298128.55	1023693.89	4.0	6.0
6	-6.1	664483.48	156772.23	4.5	6.5
12.7	-4.1	1404500.42	380585.08	4.2	6.2
12.7	-3.8	1404381.64	413160.94	4.1	6.1
6.7	-2.3	740945.51	577389.47	4.4	6.4
11.8	1.4	1308502.47	979797.75	4.1	6.1
6.6	-4.9	730236.74	289947.74	4.2	6.2
7.4	-5.1	818818.68	268221.07	4.5	6.5
6.5	-3.5	718809.26	444737.19	3.7	5.7
7.2	-5.4	796858.45	234971.15	4.4	6.4
-5.4	-5.6	-597163.11	211873.75	4.7	6.7
7.9	-4.3	873768.21	356712.38	4.2	6.2
6	-5	663915.89	278632.51	4.3	6.3
7.2	-4.3	796366.33	356481.51	4.0	6.0
13.4	0.8	1484824.72	911708.94	4.1	6.1
4.4	-4.3	486778.75	355771.26	4.5	6.5
11.8	1.8	1309221.78	1023504.15	4.0	6.0
-6.3	-1.5	-696272.21	665957.5	4.0	6.0
7.8	-4.2	862677.99	367706.14	4.3	6.3

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
9.1	1.5	1009286.34	994996.8	4.2	6.2
1.8	-0.5	199463.48	778169.59	4.3	6.3
0.7	-3.9	77701	399874.26	4.0	6.0
-13.67	-13.8	-1537268.12	-674206.81	4.5	6.5
4.4	-3.5	486671.69	444544.69	4.1	6.1
7.7	-6.1	852676.21	157988.32	4.0	6.0
7	-4.9	774477.7	290121.58	3.6	5.6
7.2	2	799191.71	1052736.81	2.1	4.1
8	-4.4	884861.98	345723.94	4.0	6.0
7.2	-4.1	796308.32	378567.48	3.7	5.7
4	-2.5	442456.63	555526.65	4.0	6.0
11.8	2.1	1309802.78	1056299.34	4.0	6.0
3.9	-4.2	431481.43	366785.26	4.5	6.5
6.7	-4.9	741296.92	289990.25	3.9	5.9
6.2	-5.4	686220.95	234429.91	3.8	5.8
5.9	-5.5	653079.13	223204.01	4.0	6.0
6.4	-5	708158.51	278799.45	4.2	6.2
12.5	-1.7	1382479.29	641286.36	4.1	6.1
5.8	-4	641501.55	389303.93	4.6	6.6
6.8	-5	752401.72	278977.1	4.1	6.1
3	-4.6	332038.11	322195.68	4.2	6.2
3.5	-0.7	387487.08	755555.62	4.2	6.2
7.5	-7.2	831548.4	36222.68	1.6	3.6
5.3	-4.6	586363.82	322710.1	4.1	6.1

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
14.7	-1.3	1626116.51	683063.92	3.8	5.8
5.5	-5.5	608822.22	223012	4.2	6.2
7.1	-4.8	785493.91	301215.28	4.1	6.1
0.8	1.5	89020.38	1001244.62	3.9	5.9
9.9	-3.7	1094733.05	423277.7	2.7	4.7
6.7	-4.9	741296.92	289990.25	3.9	5.9
-14.4	-4.2	-1591961.49	370645.57	4.4	6.4
7.9	-4.1	873704.7	378762.8	4.0	6.0
7.1	-5.9	786110.86	179640.45	4.3	6.3
12.3	1.4	1363940.34	978906.99	4.1	6.1
6.7	-4.9	741296.92	289990.25	4.0	6.0
5.3	-4.5	586336.09	333794.65	4.0	6.0
12.4	1.3	1374849.95	967825.95	4.0	6.0
-3.3	-0.3	-364831.55	800090.49	4.1	6.1
-3.9	3.5	-433541.4	1223219.27	4.1	6.1
-16.8	-14.5	-1893179.65	-732374.8	4.4	6.4
6.8	-4.2	752109.11	367411.74	4.3	6.3
7.8	-5.6	863373.62	213263.07	3.9	5.9
0.4	-10.8	44951.69	-370640.62	4.2	6.2
6.4	-6.2	708831.28	145956.02	6.2	8.2
5.3	-4.8	586424.63	300539.35	4.1	6.1
4.2	-4.7	464751.56	311325.88	3.7	5.7
8.6	-5.6	951901.51	213836.63	4.1	6.1
13.5	0.9	1496075.7	922381.92	4.0	6.0

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
13.6	0.9	1507157.5	922204.87	3.2	5.2
7.1	-4.2	785279.29	367495.85	3.9	5.9
5.3	-4.6	586363.82	322710.1	4.0	6.0
7	-7.7	776656.43	-19681.33	3.9	5.9
-9.1	-1.9	-1005754.39	620905.5	4.4	6.4
6.6	-4.9	730236.74	289947.74	4.0	6.0
13.8	0.4	1528497.23	867705.9	3.7	5.7
6.5	-4.8	719136.13	300968.26	4.2	6.2
5.9	-6.6	653747.33	101270.33	4.4	6.4
5.4	-3	597188.67	500021.53	3.9	5.9
5.9	-4.3	652625.67	356109.27	4.3	6.3
-1.1	-13.2	-123219.23	-640890.81	6.2	8.2
6.7	-4.9	741296.92	289990.25	4.3	6.3
6.6	-4.8	730195.66	301007.92	4.3	6.3
-4.9	-11.6	-547446.05	-457075.15	4.1	6.1
5.9	-4.8	652779.75	300742.94	4.2	6.2
-0.5	-6.7	-55057.66	88018.27	4.2	6.2
5.8	-6.1	642343.73	156648.92	4.2	6.2
6.3	-3.3	696683.25	466838.28	4.0	6.0
5.3	-2.8	586138.54	522182.65	4.3	6.3
7	-4.2	774222.52	367467.41	4.0	6.0
6.6	-4.8	730195.66	301007.92	4.0	6.0
7.2	-6.7	797818.75	91241.59	4.1	6.1
6.6	-4.9	730236.74	289947.74	3.9	5.9

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
6.4	-5.4	708348.16	234531.73	3.8	5.8
7	2.2	777241.75	1075153.43	2.5	4.5
7.3	-7.2	809381.31	36012.93	2.4	4.4
7	-6	775112.11	168511.9	4.3	6.3
8.6	-6.6	952794.24	103645.43	4.1	6.1
6.8	-5.5	752659.06	223685.09	4.2	6.2
7.1	-4.2	785279.29	367495.85	4.0	6.0
6.4	-5.4	708348.16	234531.73	3.8	5.8
6.1	-3.6	674602.61	433629.12	4.3	6.3
6	-3.4	663527.84	455752.23	3.9	5.9
13	-4.2	1437729.55	369880.44	4.2	6.2
5.4	-4.4	597367.14	344903.91	4.8	6.8
11.9	2.4	1321522.26	1088893.09	4.0	6.0
-2.2	-6.5	-243297.32	110588.11	4.0	6.0
11.2	-3.2	1238393.55	478187.08	2.9	4.9
12.5	1.2	1385761.06	956753.19	4.3	6.3
6.7	-4.8	741255.23	301048.19	4.4	6.4
6.7	-3.5	740918.48	444759.37	4.2	6.2
5.9	-4.5	652681.33	333964.27	2.9	4.9
6	-3.60	663548.04	433616.91	4.2	6.2
11.8	1.7	1309036.02	1012575.41	4.3	6.3
6.2	-3.5	685645.74	444705.17	6.2	8.2
10.6	-1.9	1172258.61	620358.61	2.0	4.0
5.7	-4.8	630661.24	300672.66	4.0	6.0

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
7.7	-5.8	852447.39	191115.27	4.1	6.1
5.2	-6.9	576417.78	67480.76	2.2	4.2
6.3	-0.5	-668899.44	-354701.98	4.2	6.2
4.6	-4.6	508958.88	322523.43	4.1	6.1
5.8	-5.9	642226.24	178821.3	4.0	6.0
6.3	-2.2	696741.54	588512.62	2.7	4.7
7.6	-6.5	841942.93	113714.5	4.3	6.3
11.8	1.3	1308332.5	968874.61	4.1	6.1
8	-4.4	884861.97	345723.94	4.2	6.2
6.7	-4.8	741255.23	301048.19	3.5	5.5
5.6	-4	619390.56	389265.58	3.9	5.9
8.4	-4.3	929056.74	356890.31	4.4	6.4
6.4	-4.3	707909.72	356243.73	3.9	5.9
0.9	-6.4	99974.07	121497.82	4.1	6.1
4.8	-2.8	530870.19	522199.64	3.8	5.8
12.2	1.8	1353594.91	1022729.24	4.1	6.1
12	1.2	1330336.18	957616.99	4.0	6.0
7.1	-5.2	785684.75	257016.84	4.0	6.0
6.6	-6.3	731045.75	135024.23	4.4	6.4
6.1	-3.8	674631.36	411497.08	4.1	6.1
8	-4.5	884900.82	334700.33	4.2	6.2
5.4	-4.2	597319.78	367067.04	4.2	6.2
6.6	-4.9	730236.74	289947.74	4.5	6.5
6.8	-5	752401.72	278977.1	3.7	5.7

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
11.5	0.5	1273885.52	881944.97	4.0	6.0
-2.8	-14.3	-315303.2	-764174.84	5.1	7.1
6.2	-4.6	685886.79	322988.75	4.4	6.4
5.3	-4.9	586457.72	289453.09	3.6	5.6
5.7	-5.8	631103.56	189851.78	4.5	6.5
7.6	-6.3	841769.22	135813.65	4.1	6.1
6.2	-6.2	686689.22	145820.11	3.2	5.2
6.6	-5.5	730529.94	223572.32	4.4	6.4
6.8	-7.6	754368.03	-8814.78	5.1	7.1
14.3	-1.6	1581644.33	651026.9	4.2	6.2
7.3	-0.4	808045.04	787110.23	4.5	6.5
3.8	-4.1	420410.96	377875.45	4.2	6.2
6.7	-4.9	741296.92	289990.25	4.2	6.2
0.8	0.1	88875.06	845120.6	4.4	6.4
3.7	-1.2	409482.82	699940.25	4.8	6.8
5.9	-3.6	652493.51	433604.91	3.8	5.8
12.8	1	1418670.84	934461.71	4.0	6.0
-7.4	-14.3	-833723.3	-754972.1	4.6	6.6
6.4	-5.2	708249.01	256667.04	4.1	6.1
13.7	-0.2	1516587.38	802898.09	4.1	6.1
5.4	-4.3	597342.55	355985.7	2.1	4.1
0.9	1.5	100107.58	1001231.63	4.5	6.5
6.3	-6.2	697760.23	145887.53	4.2	6.2
6.8	-3.5	751973.16	444770.72	4.1	6.1

Lat	Lon	Northing	Easting	Magnitude	Epicentral Intensity, I_o
13	-4.3	1437782.8	359033.73	4.6	6.6
-3.5	-4.9	-386744.66	288944.84	4.3	6.3
4.6	-2.3	508798.03	577668.84	4.2	6.2