

**ASSESSMENT OF IMPACT OF OIL AND GAS EXPLORATION
AND PRODUCTION ON ECOSYSTEM SERVICES AND HUMAN
LIVELIHOOD:**

**A CASE STUDY OF WEST CAPE THREE POINTS IN THE
WESTERN REGION, GHANA**

**THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA,
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DECLARATION

I, hereby declare that this thesis titled “Assessment of impact of oil and gas exploration and production on ecosystem services and human livelihood; A case study of west of Cape Three Points in the Western Region of Ghana” consists entirely of my own work produced from research undertaken under due supervision and that no part of it has been published or presented for another degree elsewhere except for the permissible references from other sources which have been duly acknowledged.

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DEDICATION

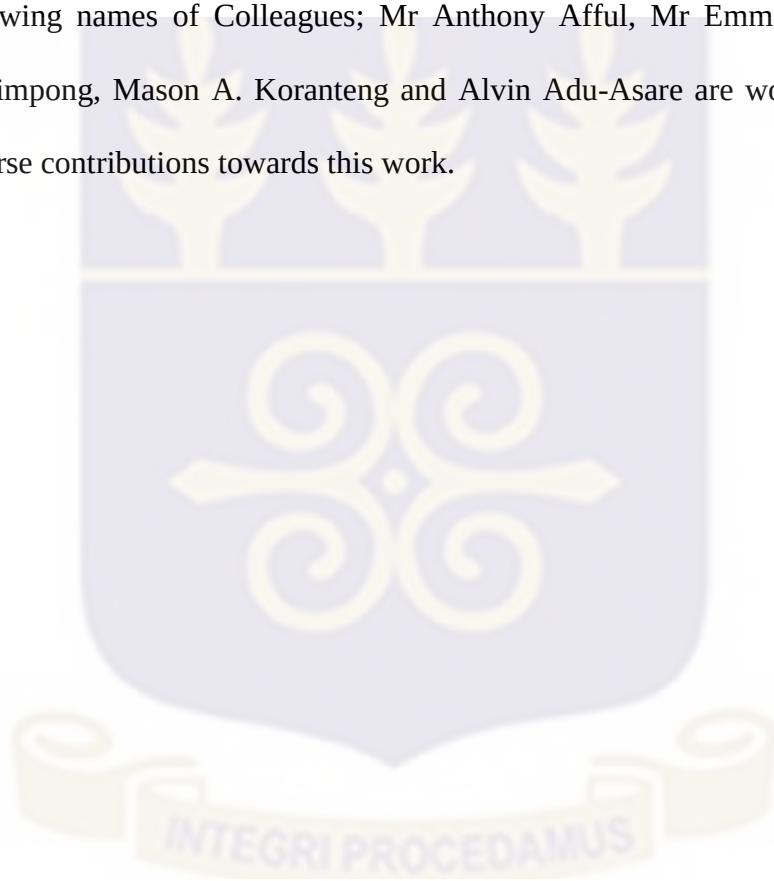
This work is dedicated to my entire family for their unflinching support and sacrifices towards the realization of my dreams.



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ABSTRACT

Ghana's oil and gas industry has been in existence for a decade now. Nonetheless, the quest for local jobs and a boost in national revenue has been a major focus with a lesser consideration for environmental and social ramifications. This study examined impact of oil and gas activities on ecosystem services and human livelihood in coastline communities West of Cape Three Points in the Western Region of Ghana. The study employed descriptive research design and purposive sampling technique. It involved a social survey and laboratory analysis of soil, sea water, borehole, hand-dug well and fish samples. Both test (main) and control samples of sea, borehole and hand –dug well water were analyzed and compared. Also analyzed were fish and soil samples. Key indicators of water quality such as pH, EC, BOD, DO, TDS and Turbidity were determined. Again were pH, Organic Carbon, EC and CEC of soil as well as heavy metals concentrations of Pb, Cd, Cr, Fe and Ni in water and fish samples. Ethos 900 Microwave and Atomic Absorption Spectrometer (AAS) were used for the quantitative determination of parameters. Data was analyzed using analysis of variance (ANOVA) at 0.05 level of significance, Karl Pearson's Product Moment Correlation at $P \leq 0.05$ and the Chi - Square to establish relationship between variables. There were significant differences amongst parameters such as EC, BOD and TDS and heavy metals such as Pb, Ni and Fe based on WHO standards. Trend of fish catch was noticed to be decreasing whiles demographic characteristics like gender, educational background were identified to influence perception of oil and gas impact on beach and shoreline recreation. Moreover, educational background, duration of stay and gender were noticed to influence public perception on visit to the beaches and shoreline.

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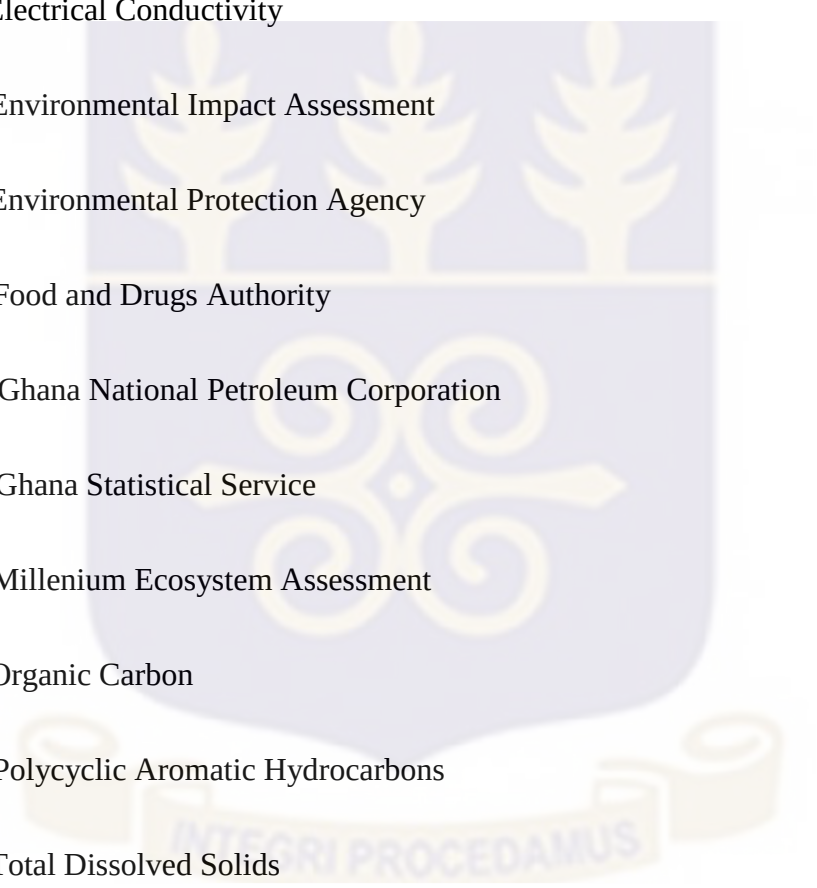
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LIST OF ABBREVIATIONS



AAS	Atomic Absorption Spectrometry
BOD	Biological Oxygen Demand
CEC	Cation Exchange Capacity
DO	Dissolved Oxygen
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
FDA	Food and Drugs Authority
GNPC	Ghana National Petroleum Corporation
GSS	Ghana Statistical Service
MEA	Millennium Ecosystem Assessment
OC	Organic Carbon
PAH	Polycyclic Aromatic Hydrocarbons
TDS	Total Dissolved Solids
THC	Total Hydrocarbon Content

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The world's market for energy has developed with lots of investments into infrastructure by countries. It culminates into several countries looking for companies to take over their lands or territorial waters for exploration with the hope to find and produce oil and gas for local jobs and to enrich national coffers in terms of revenues (Kadafa, 2012). The Energy Information Administration (EIA) (2011), reports that the midstream and downstream sectors of oil and gas is ranked the largest industry in dollar terms worldwide. The oil and gas industry offers the over 7 billion population of the world more than half of their energy needs with the rest from sources such as hydroelectric power, solar, nuclear, coal, wind, tidal and biomass products. The oil and gas industry thus contributes the largest amount of energy worldwide with 32% for Europe and Asia and 53% for the Middle East (EIA, 2011). The rates of consumption of other regions are 44% for South and Central America with 41% and 40% for Africa and North America respectively (EIA, 2011). Besides, the world's consumption of oil per year stands at 35 billion barrels with the largest being developed nations (IEA, 2016)

The oil and gas industry is a major contributor to economies such as Australia and the United States in numerous ways including direct and indirect job creation, taxation, energy security, export revenue, regional development and investment which is more than a third of Australia's business investment (KPMG, 2015). The American Petroleum

Institute reports that, in 2011 approximately 2.7 million jobs in U.S economy were supported by the oil and gas industry, yielding a GDP of about 7.3%. In addition, about 1.7 million new jobs were created with the energy boom and this number is expected to double by 2020 to become better than Saudi Arabia and Russia (EIA, 2011). According to the World Bank (2011), the contribution of the oil sector in Gabon is about 80% of total exports, 75% of government total revenue and a GDP of 50%. In Nigeria, it is 40%, 80% and 90% towards GDP, revenue and total exports respectively (EIA, 2011). For Ghana, it is earmarked to acquire US\$20 billion from the Jubilee field in the next 20 years with an average annual revenue estimate of US\$1billion (Asafu-Adjaye, 2010).

The oil and gas industry has the upstream, midstream and the downstream components. The upstream component involves license acquisition, exploration and production activities. The midstream operations involve gathering, processing and transportation, storage and other technological applications to improve efficiency. Downstream embodies crude oil refining and processing, marketing and the distribution of its products.

Crude Oil is a complex combination of hydrocarbon compounds varying from a low molecular weight to resins and macromolecules with metals and other elements. It has a great variation in colour, composition and consistency thus, different areas of production yield different varieties of crude oil. Oil composition is therefore measured based on density, Gravity in degrees, Sulphur Content (%) and Viscosity by the American Petroleum Institute (API). Total hydrocarbon content (THC) is a focus for research monitoring which shows the amounts of aliphatic and aromatic compounds. Low molecular weight hydrocarbons have straight chains of carbon atoms and form a large

percentage of fresh crude oil. Aliphatic hydrocarbons have both straight and branched chains of carbon atoms. Aromatic compounds include volatile organic compounds (VOC's) and Polycyclic Aromatic Hydrocarbons which are toxic and carcinogenic. According to US Environmental Protection Agency, the variation in PAHs mixture that arise from oil is formed coupled with its high resistance to weathering makes the compound a factor for oil pollution and monitoring.

A challenging task with oil and gas industry is the long term chronic exposures to hydrocarbons and other chemicals largely unknown (Boech et al., 1987). The accumulation of such chemicals due to oil spillage and other activities eventually become a source of concern for ecological change. Crude oil pollution occurs whenever unrefined hydrocarbons spill into the environment where it is exploited, explored or handled. Pollution is a devastating effect on biological, physical and chemical characteristics of components of an environment which further threatens human health and that of beneficial organisms (Aboribo, 2001). According to the Millennium Ecosystem Assessment (2005), there has been a rapid and extensive change in ecosystems over the past 50 years by humans. Many studies such as “problems and effects of oil industry on the Niger Delta” have also confirmed a loss in biodiversity and ecosystem services due to oil exploration and production activities (Agagu, A.A and Adu, F 2008, Ehrlich, 1981, Carpenter and Postel, 1997, McDaniel and Borton, 2002).

“An ecosystem is a dynamic complex of plants, animals and microorganism communities and the non – living environment interacting as a functional unit. Ecosystem services are the benefits people obtain from ecosystems, the goods and services derived from ecosystems that contribute towards human well-being such as food” (MEA, 2005). The

main forms of ecosystem services are provisioning, cultural, regulating and supporting service (IPPC, 2014;MEA, 2005).

Provisioning Services are the services derived from ecosystems such as food, fuel, freshwater etc. Food is mainly obtained from the forest, marine and freshwater systems. Regulating Services involve the systems of the ecosystem that act to bring about changes in temperature, pollinator abundance, pollination rates and amount of carbon sequestration.

Supporting Services of ecosystems offer habitats for various species of plant and animals. A good nutrient cycling helps plant species which animals like birds, mammals and insects depend upon. Cultural services involve intangible gains from ecosystems through experiences of spiritual enrichment, cognitive development, recreation and aesthetic values (MA 2005).

1.2 Problem Statement

Ecological balance is one of the key premises to sustainable development as espoused by the Sustainable Development Goals twelve (12) and fourteen (14). These goals seek to reinforce efforts to safeguard the natural and cultural heritage and also minimize negative environmental effects.

The Exploration and Production activities of oil and gas became intensive in the Western Region of Ghana in the year 2009 (GNPC, 2009). According to Dadzie (2015), there have since been over 21 reported cases of dead whales in the Nzema Area. Meanwhile,

places along the coastline of the Central, Greater Accra and Volta Regions of the country have not reported such major cases (Van Waerebeek et al., 2009). Also, there have been cases of washing ashore of Bitumen, oil discharges and disposal of ballast water with Sea weed or Sargarssum spp. (Ackah -Baidoo, 2013). As revealed by Owusu (2014), the Jubilee Field witnessed the spillage of toxic drilling mud on three occasions by Kosmos energy in December 2009. Based on this, the government issued a fine of \$35 million for negligence which the company challenged the legal basis (Owusu, 2014).

The above notwithstanding, fishermen are forbidden from fishing within 500 km radius around the oil rigs at the Jubilee fields in the Cape Three Points (Adjei, 2017). Hitherto, fishermen complain of poor catch even during the bumper fishing season. Little may therefore be known about the domino effect on general marine life, water bodies, coastal recreational centres and the livelihoods of members in the communities in the area etc. There are doubts of any mitigation plan implemented as proposed due to various complains from fisher folks and communities in the study area.

1.3 Justification

The study will be relevant in ensuring that coastal ecosystems are safeguarded to adequately provide for human well-being and livelihood. Undertaking such a study would provide relevant information for evidence based decision making that would benefit future generations. Thus, to offer policy and decision makers with quantitative data to help maintain all aspects of socio-economic and ecological systems around us.

In recent times, Ghana's gold mining industry brings to the fore useful lessons of chaos, loss of government revenue and jobs as deterrent. Such lessons have apparently resulted from unregulated mining activities and externalities with no payment of commensurate compensation to affected communities which the oil and gas industry must eschew.

1.4 Research Questions

1. What impacts do Ghana's oil and gas exploration and production have on water, fish and soil quality?
2. Are trends in key indicators of ecosystem services such as fish catch in coastline west of Cape Three Points changing?
3. What are the public perceptions and opinions associated with oil and gas impact on ecosystem services (quality of water, soil and fish quality) and human livelihood?
4. How has the oil and gas activities affected the beaches and shoreline recreation in the enclave?

1.5 Hypothesis

Null Hypotheses, H_0 : The exploration and production of oil and gas have no significant impact on ecosystem services and human livelihood.

Alternative Hypotheses, H_1 : The exploration and production of oil and gas have significant impact on ecosystem services and human livelihood.

1.6 Objective

The main objective of the study is to identify the impact of oil and Gas industry on ecosystem services and human well-being in coastline west of Cape Three Points of the Western Region.

Specifically, to

1. Determine the impacts of Ghana's oil and Gas exploration and production on quality of water, fish and soil using physico – chemical parameters and some heavy metals.
2. Assess the trend of fish catch between 2005 and 2014 in the enclave.
3. Evaluate public perception and opinions on how oil and gas impact ecosystem services (quality of water, soil and fish quality) and human livelihood.
4. Ascertain the public perception on the effects of oil and Gas exploration and production on beaches and shoreline recreation in the enclave.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Background to Oil and Gas Exploration and Production

Crude oil is defined as petroleum in its natural state (Ukoli, 2003). The word “petroleum” means “rock oil” or oil formed from the earth. It is a liquid mixture that contains mostly hydrocarbons, and some compounds of oxygen, nitrogen and sulphur. It can be found in different forms varying from liquids to viscous semi – solid materials and also comes in a variety of colours ranging from black or green to light yellow (Ojo and Adebuseyi, 1996). According to the American Petroleum Institute it varies considerably in density and in ranges from heavy to average or light.

Petroleum is formed from large molecules of fats, oils and waxes. This occurs in millions of years as marine organisms and other materials are deposited in layers of clay, silt and sand. The effects of heat and pressure enhance the formation of hundreds of compounds. The fluid nature of petroleum makes it able to move through the Earth upon formation. An underground reservoir of oil with a non-porous rock formation that holds the oil pool is ensured for economic gains in production.

Drilling activities usually takes place from ships or fixed platforms to extract the oil after exploration. Sea floor damage results from anchors that hold the rig as well as the impact of well emplacement system. The use of drilling mud as lubricant and the disposal of drilling cutting is a source of environmental concern as they contain polycyclic aromatic hydrocarbons (PAHs) and heavy metals that are toxic. The activity of drilling impacts the environment by smothering the seabed and also releases toxic substances (Swan et al.,

1994). Generally, the impact of drilling mud is within 150m of immediate surrounds of the drill site. However, Olsgard and Gray (1995) reported that heavy metals and hydrocarbon contamination from production platforms of the Norwegian shelf indicated evidence of contamination within 2 to 6 km away from the platforms.

2.2 Discovery of Ghana's Oil and Gas

Ghana's oil and gas industry became prominent within periods in 1970 along the Western Coast of the Cape Three Points with reference to exploratory efforts in 1896 (GNPC, 2009). In 2007, exploratory activities led to the discovery of oil and gas in commercial quantities for economic gains. After a rapid development in 2010, pumping started from two production wells in the Deep – water Tano block and the West Cape Three Points block. The unitized blocks were named Jubilee Fields to commemorate Ghana's 50th anniversary as an independent nation and is located 60km (about 35 miles) offshore (GNPC, 2009). The partners to the Jubilee Field are Tullow plc (34.7%), Kosmos Energy (23.49%), Anadarko Petroleum Corporation (23.49%), GNPC (13.75%), Sabre oil and gas (2.81%) and E.O Group (1.75%). Other discovery efforts have resulted in the Tweneboa, Enyenra, Ntomme (TEN oilfields) which started production in 2014. The Jubilee Field was earmarked for a daily production of 80,000 barrels which has currently reached 110,000 almost at the expected peak of 120,000 barrels per day. According to Willy Olsen (2011), Ghana is likely to become West Africa's third – largest producer after Nigeria and Angola, “pumping upwards of 500,000 barrels per day”.

The oil and gas enclave is predicted to involve six coastal districts of the Western Region i.e Shama, Sekondi – Takoradi, Ahanta – West, Nzema East, Ellembelle and Jomoro. These districts have majority of their communities depending on fishing as means of livelihood. Production started without recourse to any national policy vibrant enough to strictly regulate activities of the companies (Van Alstine, 2012). There have been doubt on environmental impact assessment (EIA) undertaken to adequately consider impact on coastal communities, compensations and development of affected communities (Ackah – Baidoo, A. (2012).

Hitherto, several forums have deliberated on the likely impact of the oil and gas industry on the communities and benefits citizens stands to gain.

2.3 Concept of Ecosystem Services

The concept of ecosystem services has been an initiative established in 1999 to assess effects of ecosystem change on human well-being (MA, 2005). According to the Millennium Ecosystem Assessment, ecosystem services are the benefits people obtain from ecosystems which are categorized into four (4) i.e provisioning, supporting, regulating and cultural services. For instance, marine ecosystem has fish stock that serves as food, provides recreation and improves the coastal landscape.

The Mapping and Assessment of Ecosystems and their Services (MAES) also provide a harmonized approach for ecosystem assessment (Maes et al., 2013). It adopts the Common International Classification of Ecosystem Services (CICES) which is more comprehensive for classifying ecosystem services than the Millennium Assessment (MA)

and The Economics of Ecosystems and Biodiversity, (TEEB). The CICES uses threefold division of; “Provisioning, Regulating and Maintenance and the Cultural services”. It is designed to document services that directly contribute to human well-being hence the supporting services of Millenium Ecosystem Assessment are not included. Based on the CICES, supporting services are captured by identifying the ecosystem functions that support capacity of ecosystems to contribute to human well – being. The provisioning services are material outputs while regulating services are the mediation of aspects of the environment that affect people’s well-being. The cultural services include non-material, intellectual benefits.

The two main types of ecosystem are the aquatic and terrestrial ecosystems. Terrestrial ecosystems are found at places except heavily saturated areas e.g. Forest, Desert, and Grassland etc. Aquatic ecosystems are water – bound with aquatic flora, fauna and water properties. The main kinds of aquatic ecosystem are the marine and freshwater. Marine ecosystem is the largest covering about 71% of surface of the Earth. About 0.8% of the Earth’s surface is covered by freshwater which comes in forms of lentic (slow – moving water bodies), lotic (fast -moving water bodies) and wetlands in places with soil inundated with water for a long period of time.

2.4 Impacts of oil and Gas Exploration and Production

The exploitation of oil and gas resource involves chemical and seismic wave generations, liquid discharges and gas flaring which are major sources of environmental degradation. According to Tyonongo (2008), environmental degradation is crucial as the

environment's capacity to sustain life is dependent on a good interrelationship of properties like soil, water, air, plants and animals. Tyonongo (2008), further states that "the environment has to possess the right temperature, needed oxygen and carbon dioxide in its atmosphere, good rich soil, water of its rivers, lakes, oceans and precipitation, vegetation and all other conditions that are necessary for the sustenance of life."

Environmental impacts result from exploration, drilling, production, development operations and decommissioning of facilities, nonetheless the nature and degree of impact may vary (Swan et al., 1994). The impact associated with oil spills occurs during transport, from pipeline leakages and vessel loss when large volumes can be released abruptly. Spills affect ecological systems as they result in unusual concentrations of oil on the environment. "An amount of oil approximately equal to that spilled accidentally by humans enters the oceans each year through natural seepage" (Kvenvolden and Cooper, 2003; National Research Council, 2003).

During oil and gas production, hydrocarbon reservoirs release water known as Produced Water which is brought to the surface. "The produced water is a by-product of oil production and it is either disposed of into the ocean or may be re-injected into the well to promote oil recovery" (Swan et al., 1994). Produced water can also include sea-water injected into the well to promote recovery. However, with respect to ambient seawater, produced water may have high concentrations of heavy metals such as mercury, barium, arsenic etc. as well as radium isotopes and hydrocarbons. Usually the ratio of oil and water depends on the location but increases with time towards decommission. "The proportion of water produced per barrel of oil typically ranges from around 3:1 to 7:1 although the relative amount of PW increases over time, such that in extreme cases the

fluid pumped from a well might be 98 per cent water and only 2 per cent oil” (Holdway and Heggie, 2000). At the platforms, produced water is taken through separation process and treated to about 30 mg/l hydrocarbon and disposed into the ocean. “Because this results in an upsurge in the absolute volume of oil discharged, efforts have been made in the North Sea to reduce to about 33% of oil discharge in produced water” (OSPAR, 2010).

Produced water has a temperature of between 40°C to 80°C which makes it less dense compared with ambient sea water and is thus easily affected by wind current away from production platforms. The factors of mixing and dilution with seawater makes the effect of produced water greatly felt within 1km from the platforms, although plumes may be found at distances exceeding 10km from point source (Jones and Hayward, 2003). Situations of coral discolouration have been linked with produced water dilute concentrations of 12 percent (ITOPF, 2007). Hence, much consideration is given to the location of production platforms and prevailing wind currents in relation to sensitive habitats.

Sea floor impacting activities such as anchor placement, drilling, construction, decommissioning and jetting with the sea floor for pipeline trenches cause permanent and irreversible damage to natural and cultural resource. The exploitation of oil and the associated damages have resulted in environmental degradation in Delta State in Nigeria. It causes water and land pollution with great effect on both human health, aquatic and terrestrial life due to the harmful nature of discharges (Wild, 1996). About 62.8 percent oil spill incidence takes place on farmlands in Nigeria (Nwankwo and Ifeadi, 1988). It often results in decrease in fish catch with havoc on water and food sources making fish

products very expensive. High levels of heavy metal concentration were detected in Warri area of Nigeria which endangers subsistence farming and human life (Harris – Okon, 2011).

2.4.1 Stock of fish and marine mammals

Crude oil contains different kinds of organic compounds with high levels of toxicity. It kills fish at a concentration of 4000 ppm (0.4%), (Okello, 2013). According to Samiullah (1985), denser oil residues deposited on seabed may smother fish habitat to affect spawning, nursing and feeding habits of several species.

Critical environmental factors that directly influence oil and gas impact in aquatic organisms are temperature and dissolved oxygen concentration (Sackett et al., 1975). Increased temperature from petroleum combustion cause nitrogen gas found in air around to oxidize into nitrous oxide. The presence of nitrous oxide and sulphur in oil combine with water to form acid rain. The acid rain results in the death of trees and fish kills due to acidification of water bodies. Many studies have proven that oxygen deficit affects rate of fish metabolism and decreases their ability to withstand organic and inorganic poisons (Lloyd, 1992).

Marine mammals and other fish species suffer from sound elevations by virtue of their dependence for reproduction, feeding, predation and navigation (Sakyi et al., 2012). This necessitated the issuance of a restraining order on seismic operations in the United States due to concerns over stranding of beaked whales (Gordon et al., 2004). The response of fish to oil and gas residues in water is in tandem with the general response patterns of organisms to any poisonous or stress impact. Such response patterns include stimulation, depression, loss of movement and coordination disturbances of breathing and death of

organisms (Demeke and Tassew, 2016). Seismic surveys with sound frequencies at 100Hz are known to disturb the range of hearing of marine mammals and are likely to affect other marine life (McCauley et al., 2000). Moreover, it has been established that humpback whales stay away between a distances of 7 to 12 km from operating seismic vessels with increased sensitivity (Boech et al., 19870). Borisov et al., (1994) and Kosheleva et al., (1997) also reveal that fish and other ocean mammals are highly affected by methane homologues. Similar conclusions in the Gulf of Mexico based on observation with places around offshore drilling rigs recorded extremely high levels of methane and ethane (Sackett, 1975)

2.4.2 Fish quality

Environmental impact of oil and gas is usually negative due to the toxic nature of associated compounds and the devastation that affects all forms of life. Toxicity effects may vary from subtle sub lethal behavioural to localized mass mortality of marine life. The toxicity of oil is based on factors such as the concentration of light aromatic compounds and the period of exposure of compounds.

According to Abarshi et al. (2017), crude petroleum oil and associated products have the presence of heavy metals, chemical additives like lead (Pb), Barium (Ba), Sulphur (S), Zinc (Zn), benzene and polycyclic aromatic hydrocarbons. These chemicals have been reported to be dangerous to the health of living organisms when ingested or metabolized (Akutam, 2012)

The less dense crude oils and their refined products like kerosene and petrol cause acute toxic effects because they have higher amounts of low molecular weight aromatic compounds. Quite a large amount of lighter toxic components is able to spread through

water column instead of evaporating from the sea surface. This often results in narcosis or mortality of intertidal and shallow sub-tidal benthic fauna like the bivalve molluscs, crustacean and also free-swimming fishes.

According to report from the University of Lagos, samples of water from sources such as sea, river, borehole, lagoon and beach in the Niger Delta Region contains 70% of Benzo[a] pyrene, with a concentration between 0.54 to 4.0 µg/l which exceeds the World Health Organization (WHO) recommended level of 0.7 µg/l (Nduka et al., 2012). The level of the compound in the water samples further indicates that sediments which are food sources of fish and other marine organisms will have greater concentrations. The persistent nature of toxic synthetic organic compounds leads to their increased concentration at higher levels along the food chain often stored in fatty tissues due to their hydrophobic properties resulting in bioaccumulation (McGuinness and Dowling, 2009). Hence, the carcinogenic nature of Benzo [a] pyrene as an organic compound with high levels in water samples becomes crucial as past experiences consolidate increased cases of cancer and respiratory problems in line with oil pollution in the Niger Delta.

According to Burger et al., (2002) fish species may be used to determine pollution of heavy metals in aquatic systems since they are found at different trophic levels to act as primary, secondary and tertiary consumers.

2.4.3 Water quality

Water remains enrichment for the sustenance of plant and animal life (Gray, 1997). The United Nations reports that, the shortage of quality water could impact negatively on the economic growth of countries with repercussions such as food insecurity and global conflicts.

Oil and gas installations come with discharges such as produced water, process water, sewerage, sanitary and domestic waste, spills and leakages (E&P Forum/UNEP, 1997). The drilling of exploratory wells and the eventual crude oil production bring about these discharges. As part of the discharged fluids are complex mixture of organic and inorganic compounds, trace and heavy metals (Sadiq et al., 2002). Hence, the release of produced water into marine waters and other water sources affects the levels of dissolved oxygen making it difficult for the survival of fish and other organisms (Lloyd, 1992). According to Sam-Okyere (2010), the release of waste water into water sources demands special attention as it risks the life of living organisms.

The drilling process as part of the production stage of oil and gas require between 2 to 7 million gallons of source water. This affects both quality and quantity of water for aquatic ecosystem and human consumption (Entrekin et al., 2011). The high amount of water used in development of oil and gas becomes a source of concern as it interrupts with the way pollutants can be processed, decreases the quantity and compromises quality of drinking water (Hanson et al., 2005). Available records also indicate that oil spill is a major cause of water pollution, canalization and waste discharge into fresh waters, swamps and the sea (UNDP, 2006). Organic substances which form a major part of crude oil and petroleum products to a large extent increase the heavy metal concentration upon release into water bodies. Meanwhile, smaller amounts of heavy metals such as lead (Pb), Cadmium (Ca), Mercury (Hg), Chromium (Cr), Cobalt (Co), Iron (Fe) and Copper (Cu) above recommended levels are known to affect humans and the aquatic ecosystem (Bowen, 1979, Ademoroti, 1996). According to Ellis (1989) there is much emphasis on the high presence of Lead (Pb), Chromium (Cr) and Iron (Fe) as

their toxicity often leads to chronic exposures in aquatic animals. The occurrence of spills into freshwater and marine surroundings is shown to affect both the variety of species and numbers of macro-invertebrate's due to oil sorption and the coating of substrates (Blackburn et al., 2014). Also Kulkarni,(1997) indicated that, the release of high amounts organic matter pollutants into waters leads to higher levels of Biological Oxygen Demand (BOD), faecal coli forms and total dissolved and suspended solids with its effects on water quality and the sustenance of animal life.

2.4.4 Soil quality

The toxicity of crude oil is a major source of worry that arises from every pollution related to crude oil. This is in terms of the hazardous nature of hydrogen and carbon containing compounds to soil – borne organisms as well as the possible contamination of the food chain. The presence of crude in pore spaces in soil has been reported to expel air, deplete oxygen reserves and impedes all forms of gaseous exchange between the atmosphere and soil thus limiting the survival of soil biocene as it is denied elements essential for growth and development (Ayotamino and Kogbara, 2006).

According to Idoniboye (2000), crude oil pollution spells for more hazardous consequences for soil and soil -borne organisms than air pollution because whatever is absorbed by plants would be rich in the content of water soluble constituents of petroleum oil some of which are toxic to plants. Crude petroleum oil production and its potential spillage unto the soil alter the carbon – nitrogen ratio and lead to nitrogen deficiency which can in turn threaten the survival of soil biota (Jobson et al., 1974). The removal of vegetative cover and topsoil during oil and gas development hampers natural carbon sequestration enhances carbon emissions through biomass loss and soil erosion

(Bruce et al., 1999). According to Jones and Pejchar (2013), oil and gas in Colorado and Wyoming is the cause of loss of high biomass carbon as activities are carried out in areas with most of land cover rich in carbon.

With reference to Osuji and Nwoye (2007), cation exchange capacity is one major basis for soil fertility thus the lack of some mineral elements in the soil becomes detrimental for plant growth. Soils under gas flaring are usually infertile due to excessive heat coupled with high acidity resulting from acid rain (Patin, 1999). This eventually renders soils unproductive as solubility and the ability to absorb nutrients is affected. According to Alakpodia and Ogidiolu (1995), exchangeable cations in soil under gas flaring is low with a mean value of far below 20 milliequivalent per 100g of soils to achieve high soil fertility status. Moreover, Atuma and Oje (2013), noted that organic matter and total nitrogen decline under gas flaring were consistent with increasing distance highly attributable to intense heat which hampers the formation processes of organic matter and nitrogen.

Alakpodia (2000), in his work on “soils under gas flares in the Niger Delta” recorded low figures of 1.83% and 0.08% as mean values for organic matter and total nitrogen respectively. Alakpodia (2000), asserted that the intense heat from flares accounts for the low values recorded and besides the activity of gas flaring leads to acidity in soils with pH ranges of between 4.3 and 5.8.

2.4.5 Perceptions on human livelihoods and shoreline recreation

Although coastal areas form only 10% of the total land area of the earth's surface, over 60% of the world's population use it as places of abode (Lakshimi & Rajagopalan, 2000, Tudor & Williams, 2001). However, the lack of jobs restricts the coastal population to

only fishing which tends to make their lives impoverished upon exploration and production activities of oil and gas. Oil exploration activities lead to income losses, migration and negative social vices such as prostitution, truancy and increased school drop outs, wars, corruption and kidnapping. The Niger Delta State has turned out to be a region of absolute confusion with influx of armed gangs noted for kidnapping and routine violence (Bloomfield, 2008). Again, Nigeria and Cameroon witnessed a challenging situation of disagreement over the oil -rich Bakasi Peninsular which attracted the intervention of an international arbitration.

In many nations of oil production like Nigeria, oil exploration has impacted negatively on the marine ecology which serves as source of livelihood. The people in such oil-bearing communities suffer loss of fish catch, extreme poverty and loss of livelihood, social conflicts and community displacement. Fishermen are compelled to move away from drilling sites to allow for drilling activities that disrupts fishing activities and reduces the amount of catch. According to the World Rainforest Movement bulletin (2009), in the Philippines oil exploration has caused dwindling fish population as disappearance of local fishes is impacting negatively the livelihood of over 200,000 fisher folk.

According to Eteng (1997) oil exploration and production has seriously affected the social and the physical environment of communities in the Niger Delta threatening agricultural production and the entire livelihood of the people. A World Bank report in 2011 also indicates that the Niger Delta lags behind in terms of education with the unbearable implications for the nation's future. Moreover, the Ogoni land is said to have suffered devastation in the hands of Shell Company and other multinationals due to

irresponsible extraction of oil and gas (Boele et al., 2001). This to a large extent affects the capacity of fauna and flora to thrive with a trickle – down effects on the food chain.

Ghana is not an exception as communities in the oil and gas enclave cry for help on the loss of their livelihoods and other negative impacts. For instance, is the spill of about 699 barrels of oil-based mud by Kosmos Energy in December 2009 and 37 litres of oil by Tullow due to link pipe rapture in the Jubilee Fields (Owusu, 2014, Anon, 2010). Such discharges from drilling processes goes a long way to affect the marine ecosystem and undermines the efforts of fishermen in their activities as a major means of livelihood of communities at the Cape Three Points (Anon, 2010). The members and especially the youth of these fishing communities have therefore shifted attention unto commercial motor – bike riding for meagre amounts to be able to make ends meet. According to Basina (2006), oil activities has led to the washing away of shorelines in the Delta state Region due to the increased numbers of deep – sea oil and gas activities.

The beaches and shoreline of coastal marine environment offer a great source of recreation with its conducive ambience. This has helped to create over 300, 000 jobs in the tourism industry (EU, 2011). However, many countries now come face to face with the problem of severe beach erosion leading to shoreline devastation caused by rising sea levels, sinking land masses and deep-sea exploitation of oil and gas. Oil activities lead to massive erosion of shoreline due to intensive marine exploration and exploitation activities (Schlacher et al., 2007). This definitely affects the number of visitors likely to visit the sea shores for entertainment and recreation with its impact on the GDP contribution by the countries tourism industry. According to Dadzie (2015), the incidence of sea weeds (Sargarssum) along the beaches of communities in the Cape Three Points

constitute the main visual pollution in greater quantities. The quick and the sudden spread of the sea weeds upon commencement of oil production in the enclave consolidate the belief of negative impact in the enclave. The weeds are rendering the shoreline useless as fresh air they use to enjoy now comes smelly. It therefore predisposes high sense of reluctance to potential tourists towards recreational centres in the study area. Resorts will have to take up the onerous task to promote clean and serene surroundings clients will accept (Aryeh-Adjei et al., 2015).



CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of Study Area

The study was conducted mainly in the coastline communities West of Cape Three Points (a small peninsula), which embraces the following districts: Parts of Ahanta West, Ellembelle and Jomoro districts of the Western Region. The area falls between latitude 4°.45'N - 5°.02'N and longitude 2°.04'W - 2°.53'W. The Ahanta West District is located southernmost point of the country and the entire West African Sub-Region. It is bounded to the East by Sekondi – Takoradi Metropolitan Assembly (STMA), the West by the Nzema East Municipality and to the North by Mpohor Wassa East District and Tarkwa-Nsuaem Municipality and the Gulf of Guinea to the South. The Ellembelle District shares boundaries with the Jomoro District to the West, Wassa Amenfi West District to the North and the Nzema East and Tarkwa Nsuaem to the Southeast and East respectively. The Jomoro District is also located in the South-western part of the Western Region of Ghana. It shares boundaries with Wassa - Amenfi and Aowin – Suaman to the North, Nzema East to the East and La Cote D'Ivoire to the West and the Gulf of Guinea to the South.

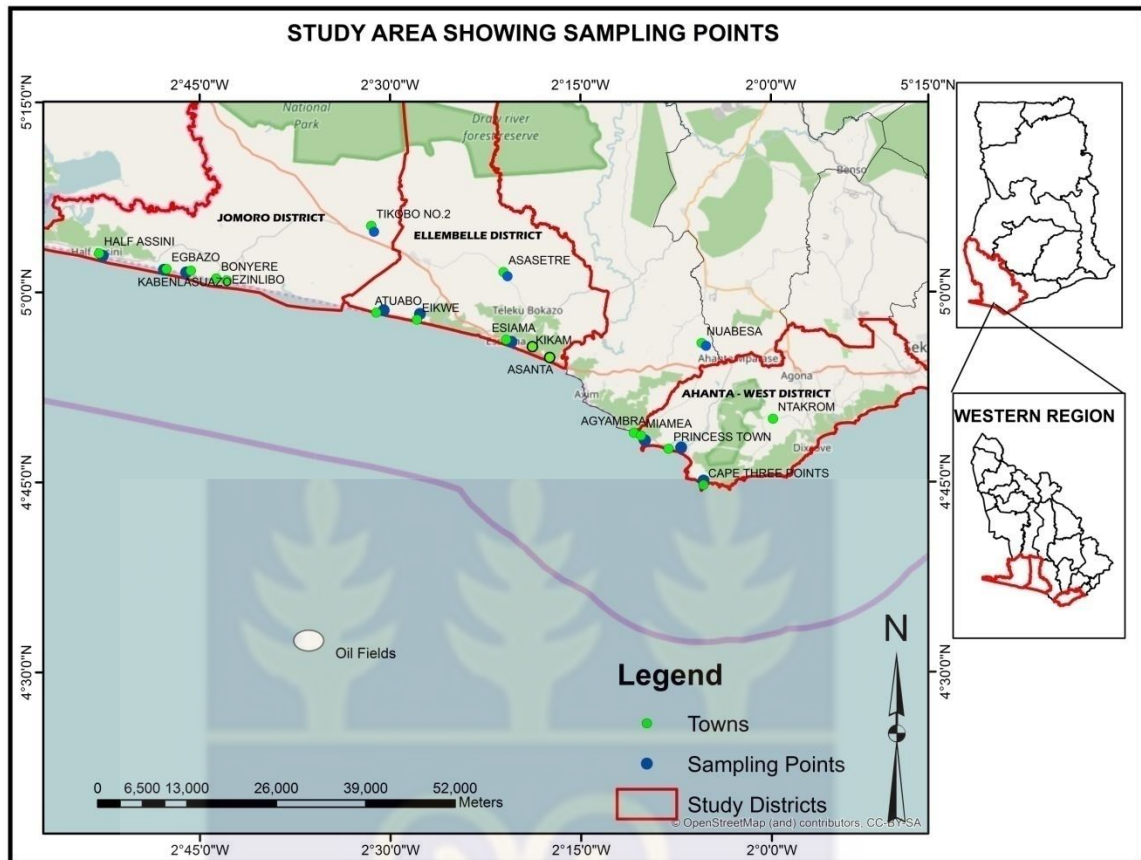


Figure 3.1: study districts, communities, and sampling points.

3.2 General Environmental Conditions

3.2.1 Climatic conditions

The Ahanta West district is found in the south-western equatorial climatic zone of Ghana. The highest mean temperature is 34°C which is recorded between March and April with the lowest mean temperature of 20°C experienced in August (GSS, 2010). It has a bimodal annual rainfall of over 1,700 mm with the season starting in April and ending in September. Similarly, the Ellembelle and Jomoro districts lie within the semi – equatorial climatic zone of the West African sub – region with an all – year-round rainfall. The

average annual rainfall figures range from 1250 mm to 2000 mm with an average temperature of 29.40°C (GSS, 2010). The Jomoro district is also characterized by a high rainfall in two wet seasons and a uniformly high temperature. It has the Equatorial Monsoon and owes its rains to low pressure areas over the Sahara to attract winds from the south of the equator.

3.2.2 Topography

The Ahanta West district is found on the coastal belt of the country at an elevation ranging between 0 and 121m above sea level (GSS, 2010). The land is generally flat with a few isolated hills between 20 to 40 meters above sea level at some towns notably Cape Three Points, Princess Town and Egyambra which has a plateau. However, the Ellembelle district is generally undulating with the highest point at about 450 ft. above sea level (GSS, 2010). The Jomoro district has as part of its south – central part an area of rolling granite with steep – sided small round hills rising from 200 m – 600 m. The coast is made predominantly of flat upland areas and steep valleys with few highlands.

3.2.3 Soil

The Ahanta West district has four main categories of rocks; lower Birimian, Dixcove granite, Cape Coast granite and Tarkwaian. These have resulted in the formation of sandy, clay, loam and moderately well drained clayey loam for production of cash crops such as Cocoa, Rubber, oil palm and food crops. The soil in the Ellembelle is mainly ferric acrisols with about 98% dysric fluvisols (GSS, 2010). The Jomoro district forms a uniform sandy clay with the coastal sand consisting of very young sand and alluvial deposits along and behind the shoreline.

3.2.4 Vegetation

The Ahanta West district lies within two broad vegetation belt, the strand and Mangrove and the Rainforest. The northern part falls largely within the high Rainforest Vegetation Zone and thus supports growth of rubber and oil palm while the part within the strand and mangrove supports coconut growth. The Ellembele district has a moist semi – deciduous rainforest in the northern part but turns into secondary forest southwards mainly due to anthropogenic activities such as deforestation (GSS, 2010). It has several timber species and other non – timber forest products like rattan, bamboo among others. The Jomoro district lies within the forest belt of Ghana. It bears a Tropical Rain Forest with evergreen scenery with vast variety of plant species. There are also major areas of swampy forest which remain uncultivated due to waterlogged conditions for most times of the year (GSS, 2010).

Research Design

3.3 Descriptive research design

The descriptive research design was used. The descriptive design allows the researcher to combine qualitative and quantitative methods of data collection. Descriptive research organises, tabulates, describes and depicts events based on a gathered data (Glass & Hopkins, 1984).

The study was mainly conducted in three coastal districts of the Western Region namely: Ahanta West, Ellembele and Jomoro district all found in the oil and gas enclave. These districts were selected due to their closeness to the oil and gas fields and also the large stretch of shoreline in the coast. The study involved the determination of physico-

chemical parameters of water samples (seawater, borehole water, well water) and soil as well as heavy metals in fish samples as proxy indicators of oil and gas impact on ecosystem services including a social survey. Test and control samples were taken from different sites in the study area based on accessibility to the sites and proximity to the oil fields. The test samples were collected from the coastline where oil and gas activities were undertaken. The control samples were however collected from areas where oil and gas activities were not undertaken. The control samples of sea water were taken from the Shama district because it is about 200 km from the oil fields. On the other hand, control samples for boreholes and hand dug wells were taken from Tikobo (II), Asasetre and Nuabesa (12.4 km, 9.7 km and 13.6 km respectively from the coastline). A social survey conducted involved the use of questionnaires, focus group discussions and interviews of the respondents.

3.4 Data and Sources

The study relied on both primary and secondary data. The primary data were collected through, questionnaires, interviews, focused group discussions, field observations and the results of laboratory analysis. Secondary sources of data on oil and gas and ecosystem services were from content analysis of literature gathered from various journals, publications and other relevant materials from institutions such as the Environmental Protection Agency, (EPA), Fisheries Commission, Friends of the Nation, Ghana Statistical Service (GSS).

3.5 Target population and Sample Size

Target population comprised local fishermen, farmers, district environmental officers, community leaders as well as beach resort managers. All the categories were considered

for the study because of their association with the oil and gas production and services of ecosystem. The target population helped to obtain more insightful information to support the study as varied views was acquired and compared.

An estimated total household of 1,115 across Ahanta West, Ellembelle and Jomoro Districts was considered as the sampling frame. The below statistical model known as the *Slovin's formula* was used to determine the sample size at a 95 percent (%) confidence level with 5 percent (%) margin of error.

i.e $n = N / (1 + N(e^2))$

$$n = 1115 / (1 + 1115(0.05^2))$$

$$n = 1115 / 3.7875$$

$$n = 294.39$$

$$\approx 294$$

Where n = sample size

N = Sampling frame/Population size

e = error of margin/level of precision

1 = a constant

According to Anderson et al., (1998), with emphasis on a large sample distribution theory, reliable estimates can be obtained from samples above 100. This notwithstanding,

similar studies in the area by have used a sample size beyond 100 to gain acceptable valid and consistent results (Yeboah et al., 2012).

Hence, 294 persons constituted the sample size that was interviewed in five communities selected from each of the three districts. Communities selected from the Ahanta West district were; Cape Three Points, Princess Town, Miamia, Egyambra and Ntakrom. The Jomoro district had, Half Assini, Egbazo, Kabenlasuazo, Ezinlibo and Bonyere. The rest from the Ellembele district were; Atuabo, Essiama, Eikwe, Kikam and Asanta. These study communities were selected based on accessibility and close proximity to the oil and gas fields.

3.6 Research Instrument

Questionnaires, interviews and focused group discussions were used to collect or retrieve information from the respondents. A total of two-hundred and ninety-four (294) persons were interviewed using open and closed - ended questions to collect both qualitative and quantitative data. The various sections of the interview schedule for data collection were demographic characteristics, oil and gas activities and quality of water, fish and soil, the trends in fish catch and impact of oil and gas on human livelihood and shoreline recreation. (Appendix 1). The distribution of questionnaire amongst communities in the various districts was based on size of population. (Table 3.1)

S/N	NAME OF COMMUNITY	NO. OF QUESTIONNAIRE	DISTRICT
1	Half Assini	21	Jomoro
2	Egbazo	20	Jomoro
3	Kabenlasuazo	18	Jomoro
4	Bonyere	20	Jomoro
5	Ezinlibo	18	Jomoro
6	Atuabo	20	Ellembelle
7	Eikwe	20	Ellembelle
8	Essiama	21	Ellembelle
9	Kikam	20	Ellembelle
10	Asanta	18	Ellembelle
11	Ntakrom	18	Ahanta West
12	Egyambra	20	Ahanta West
13	Miamia	20	Ahanta West
14	Princess Town	20	Ahanta West
15	Cape Three Points	20	Ahanta West

Table 3.1: Distribution of Questionnaire in various communities

3.7 Sampling procedure

The study relied on purposive (judgmental) sampling technique as a selective method with particular groups as target. Three coastal districts (Jomoro district, Ellembelle and Ahanta West) were selected from which targeted groups (Farmers, local Fishermen, Beach Resort Managers, District Environmental Officers and Community leaders and members) were obtained based on quotas. Questionnaire was administered in five (5) communities in each of the three (3) districts of the study area. (Table 3.1)

3.8 Social Survey

The questions were interpreted in the local languages (Akan, Ahanta and Nzema) for the respondents who could not read or write. This ensured effective communication and made information retrieval more easy and accurate. Aside the use of questionnaire as the major instrument for the study, a focused group discussion was also held including other informal discussions to serve as additional source of information. The survey process lasted for a period of two (2) weeks and the total number of questionnaires retrieved was two-hundred and sixty three (263) due to reluctance on the part of some respondents.

The focused group discussion was organised at Egbazo, a coastal community in the Jomoro district. The forum discussed the trend of fish catch in the area, impact of oil and gas activities on livelihood and ecosystem service indicators such as amount of fish catch, quality of fish and water. Also, were influence of oil and gas activities on shoreline recreation and visits to the beaches in the study area, (Plate 3.1). Respondents at the time exhibited their absolute disgust towards happenings such as the loss of livelihood and how making ends meet in a day has been challenging. Other members hesitated to join

the discussion since according to them, there has been several surveys without any feedback.



Plate 3. 1: Focus group discussion at Egbazo near Half Assini

3.9 Sample Collection.

3.9.1 Sampling of Sea water, Borehole, Well water, Fish and soil.

Sampling was undertaken for both test and control samples of sea water, borehole water and well water from different sites in the study area as well as sites outside the study area away from the coastline. Thus, Half Assini and Kabenlasuazo communities were selected from the Jomoro district, Atuabo and Eikwe from Ellembelle district whiles Cape Three Points and Princess Town were selected from Ahanta West district. As earlier indicated

communities distant away for control samples were: Tikobo (II), Asasetre and Nuabesa, a community from each district.

A half - litre plastic bottles washed with detergent and rinsed with distilled water were used to collect two (2) test samples each of Sea water, Borehole and Hand –dug well water from sites in the communities in each of the three districts of the study area. To serve as control were two (2) samples each of Borehole and Well water taken from pristine distant communities (i.e. Tikobo (II), Asasetre and Nuabesa) away from the coastline and also two (2) samples of sea water collected from different sites in the Shama District.

The soil samples were taken at regular intervals at two sampling sites also in each of the three districts where a triangular quadrat was thrown and soil collected from it extremes using a soil auger at a depth of between 0 to 20cm and content placed into sampling bags. The communities selected for soil samples were based on close proximity to the oil and gas fields. In total, Six (6) test samples each of sea water, borehole and hand-dug well water were obtained with their six (6) corresponding controls. Also were six (6) soil samples, two each from the three districts in the study area.

The sampling process was carried out for two consecutive times for the samples of fish. Three (3) samples of fish made of two (2) fish species; Blue fish (*Pomatomus saltatrix*) and Weak fish (*Cynoscion regalis*) were obtained from contracted commercial catches by the local fishermen on the 6th and 7th of March at ,Essiama, Half Assini and Shama. The Blue fish was obtained from Shama whiles the weak fish was obtained from Essiama and Half Assini communities. The water and fish samples were kept in ice chest at 4°C to avoid microbial activity when they were being transported to the Ecological laboratory of

the University of Ghana. The samples were identified, labelled and kept in a freezer for analysis.

3.9.2 Preparation of Soil, Fish and Water Samples

The samples of soil were air-dried, grinded and passed through a 2 mm sieve. They were kept in a poly bag and labelled appropriately at the Ecological laboratory of the University of Ghana for the physical and chemical analysis.

The fish samples were taken from freezer and allowed to thaw. They were washed with distilled water and dried on a tissue paper. A portion of the edible muscle tissue from the dorsal part, gills and intestines were removed and homogenized for each of the species. A 10.0 g of the homogenized amount of each species of fish was kept in 25 ml Nitric acid overnight followed by digestion on a heating mantle after the addition of a 10 ml Sulphuric acid until a clear light-yellow solution was obtained (Plate 3.2).



Plate 3.2: Preparation of fish samples for laboratory analysis

A 3 ml of 65% HNO₃ and 4 ml of per chloric acid were added to 100cm³ distilled samples of water. The resulting solution was placed in an Ethos 900 Microwave for 30 minutes at 250 W for digestion. The digested solution was topped up to 200 ml by adding distilled water. The solutions were aspirated in the spectrometer following specifications outlined for each element in the manual of the Atomic Absorption Spectrometer (AAS).

3.10 Determination of heavy metals in water and fish samples

Standard procedures were followed for the quantitative determination of heavy metals. The dissolved heavy metal concentrations in the water and fish such as Iron (Fe), Lead (Pb), Cadmium (Cd), Nickel (Ni) and Chromium (Cr) samples were determined using direct flame Atomic Absorption Spectrometry (AAS) of model PinAAcle 900T by using different Cathode lamps.

3.11 Determination of physico-chemical parameters of water and soil Samples

All the water analyses were carried out using the appropriate certified and acceptable international procedures outlined in the standard methods for the examination of water (APHA, 1998). The physical parameters such as dissolved solids (TDS) and turbidity were determined. Also, were the chemical parameters such as pH, Electrical Conductivity, Biological Oxygen Demand (BOD), Dissolved Oxygen (DO) and Salinity. Turbidity was measured using turbidimeter (Model HACH 2100P) NTU and total dissolved solids (TDS) measured with a portable digital TDS meter (Model HI 99301) whilst salinity was measured using a hand – held refractometer.

For soil were Organic pH, Organic Carbon (OC), Conductivity and Cation Exchange Capacity (CEC) using HACH model multi – probe meter (U – 50 series).

3.12 Data analysis

Raw data collected for physico-chemical parameters of sea water, borehole, fish species and hand dug well as well as soil and social survey were entered into Microsoft Excel spreadsheet version 2010. The data was finally imported into Statistical Package for Social Sciences (SPSS) software version 22.0 for statistical analysis. The means, maximum and minimum ranges for the various parameters and frequencies were generated. Analysis of variance (ANOVA) at 95% confidence level (5% level of significance) was used to test for the significant differences in concentrations among the various water and soil sources as well as fish species. Statistical significance was accepted at $P \leq 0.05$. Karl Pearson's Product Moment Correlation analysis was carried out to establish the strength and direction of relationship between the parameters of the water samples and soil samples. A correlation coefficient of $r \geq 0.5$ was deemed statistically significant. The Chi-square test was also used to establish the relationship between the effects of oil and gas exploration and production and shoreline/beach recreation based on public perception.

CHAPTER FOUR

4.0 RESULTS

This chapter presents the results on the findings of the study. The results are sectioned into four (4) parts; the impact of Ghana's oil and gas exploration and production on ecosystem service indicators (water quality, soil quality and fish quality). As earlier indicated, the study used physico-chemical variables as proxy indicators of ecosystem quality and the extent to which they have been affected directly or indirectly by the oil and gas exploration and production activities. The trend of fish catch from 2005 to 2014 in the enclave, public perception and opinions on how oil and gas exploration and production has impacted ecosystem services and human livelihood as well as the beaches and shoreline recreation in the enclave.

4.1 Assessment of Impact of Oil and Gas on Water Quality

4.1.1 pH

The mean pH values of test water samples ranged from a minimum of 6.1 (borehole) to a maximum of 7.6 (sea water) (Figure 4.1). The pH of the control water samples for sea water, hand dug wells and boreholes showed higher variations compared to the test water samples used to determine the impacts of oil and gas due to release of produced water etc. Analysis of variance (ANOVA) at 95% confidence interval showed that the pH differed significantly among the different water sources ($P \leq 0.05$) (Appendix 2). When the Bonferroni pair wise multiple comparison was used to separate the means, it showed that, there were no statistically significant differences in pH among test and control water samples from borehole and hand dug well and also the samples of sea water (Appendix 3).

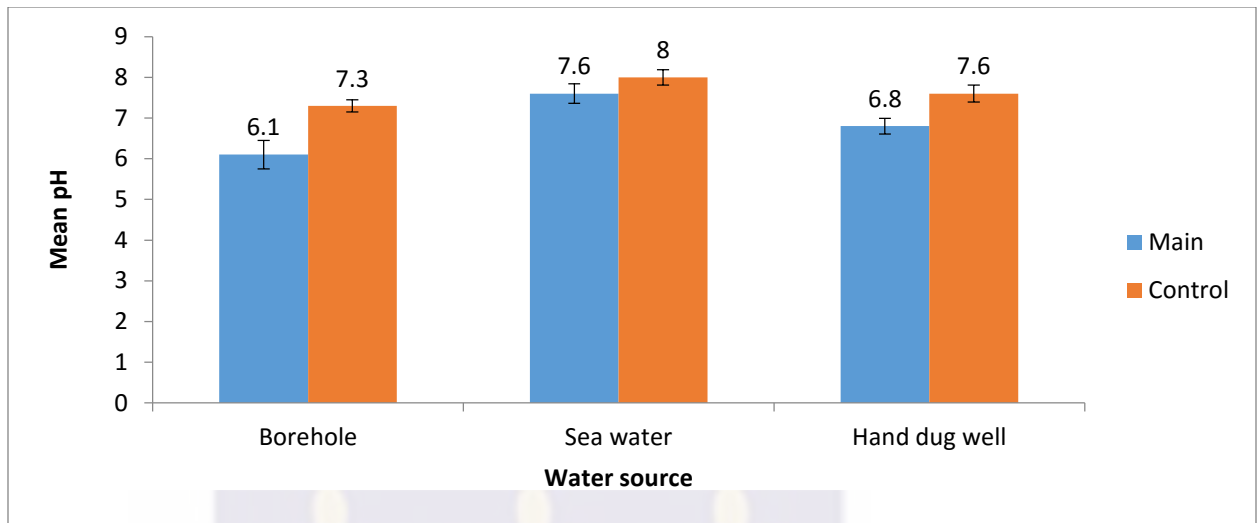


Figure 4. 1: Mean pH of water samples from study sites.

4.1.2 Electrical Conductivity (EC)

The mean conductivity of the water samples ranged from a minimum of 623 μ S/cm (hand dug well) to a maximum of 4618.9 μ S/cm (Sea water) (Fig 4.2). The control samples from all the water sources used to determine the impact of oil and gas exploration recorded low variations in conductivity compared to the test (main) water samples. Analysis of variance (ANOVA) at 95% confidence interval showed that conductivity differed significantly among the different water sources ($P \leq 0.05$) (Appendix 2). Bonferroni pairwise multiple comparisons showed that, there were statistically significant differences in conductivity among sea water, hand dug wells and boreholes with that of corresponding control samples (Appendix 3).

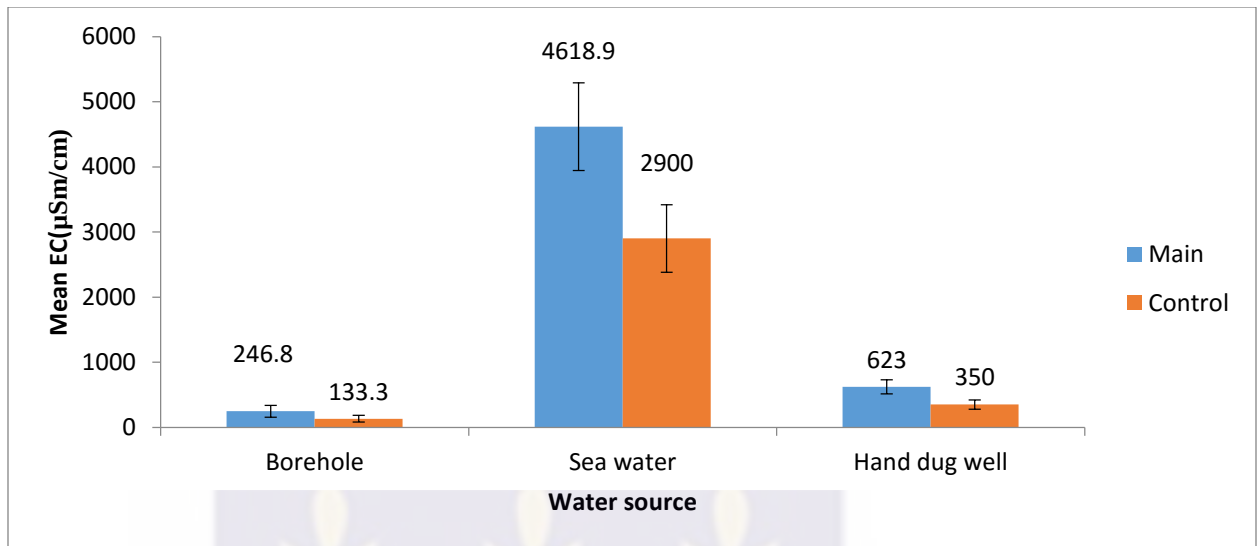


Figure 4.2: Mean conductivity of water samples from study sites

4.1.3 Biological Oxygen Demand (BOD)

The mean BOD ranged from 4.31 mg/l (Sea water) to 6.08 (borehole) (Figure 4.3). Analysis of variance (ANOVA) at 95% confidence interval revealed statistically significant differences in BOD among the water sources, ($P \leq 0.05$) (Appendix 2). The BOD of the control water samples were relatively lower compared to the water samples that were used to determine the impacts of oil and gas on water resources. Bonferroni pair wise multiple comparisons, showed that there were no differences in BOD between borehole water and hand dug well water but were significantly different from sea water.

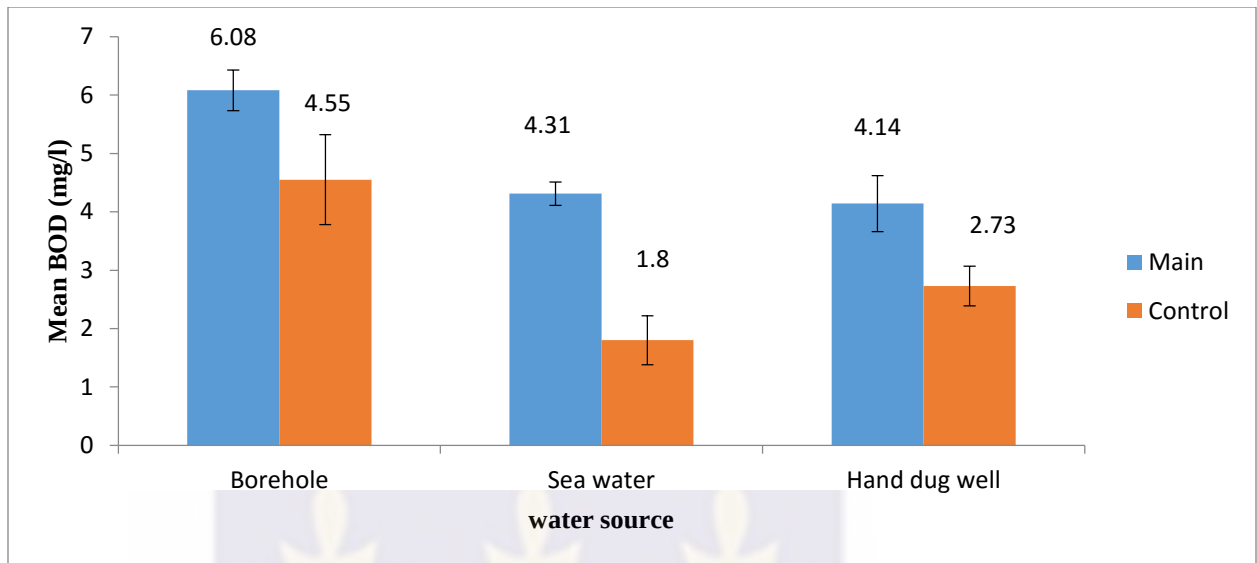


Figure4. 3: Mean BOD of water samples from study sites

4.1.4 Dissolved Oxygen(DO)

The mean DO of the test water samples ranged from a minimum of 8.29mg/l (Hand dug well) to a maximum of 10.37mg/l (borehole) (Fig 4.4). Analysis of variance (ANOVA) at 95% confidence interval showed the dissolved oxygen did not differ significantly among the different water sources ($P \geq 0.05$) (Appendix 2). However, the DO of water samples showed higher variations compared with the corresponding control samples. The Bonferroni pair wise multiple comparisons, showed that there are no significant differences between the samples (Appendix 3).

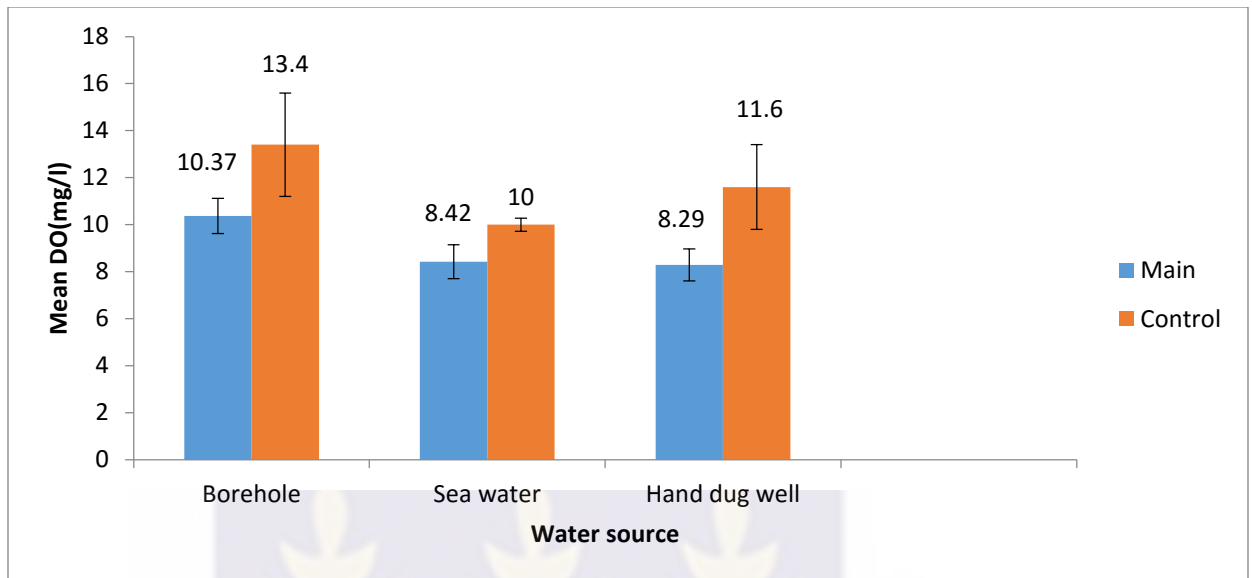


Figure 4.4: Mean dissolved oxygen (DO) of water samples from study sites

4.1.5 Salinity

The mean salinity ranged from a minimum of 0.08mg/l (borehole) to a maximum of 29.9mg/l (sea water) (Fig 4.5). The salinity of the sea water samples and corresponding control samples showed higher variations compared to that of borehole and hand dug wells. Analysis of variance at 95% confidence interval revealed statistically significant differences in salinity among the water sources ($P \leq 0.05$) (Appendix 2). Bonferroni pair wise multiple comparisons, showed that there were no differences in salinity between hand dug wells and boreholes but was significantly different from sea water.

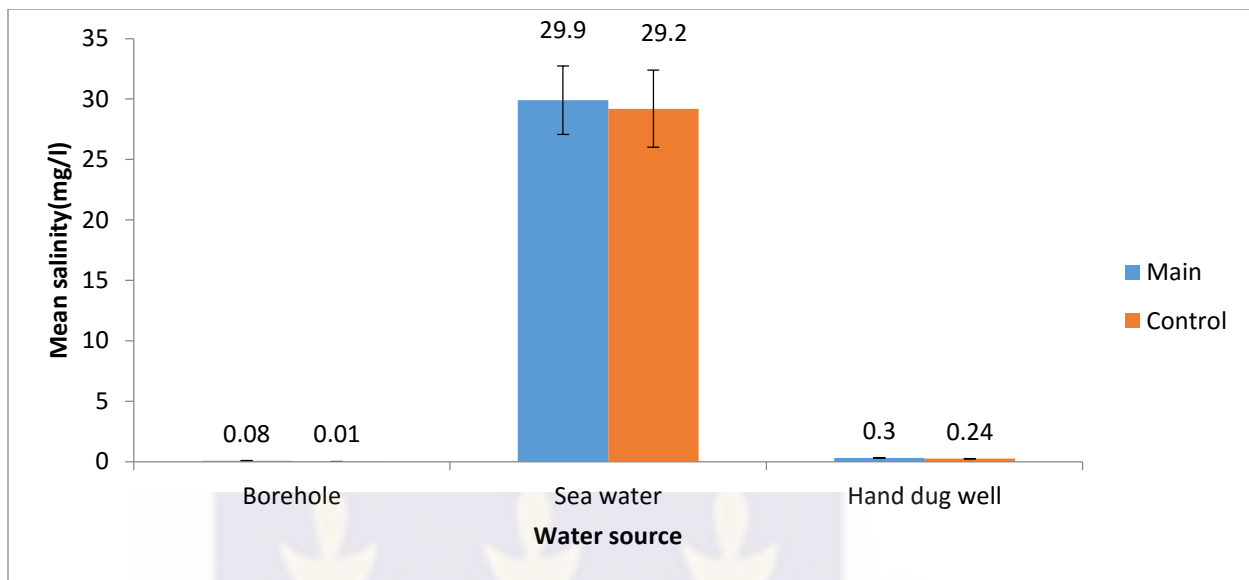


Figure 4.5: Mean salinity of water samples from study sites

4.1.6 Total Dissolved Solids (TDS)

The mean TDS of the test water samples ranged from a minimum of 161mg/l (borehole) to a maximum of 2766.7mg/l (Sea water) (Fig 4.6). The control samples from all the water sources used as reference samples to determine the impact of oil and gas exploration recorded low variations. Analysis of variance (ANOVA) at 95% confidence interval showed that TDS differed significantly among the different water sources ($P \leq 0.05$) (Appendix 2). Bonferroni pair wise multiple comparisons showed that, there were statistically significant differences in conductivity among test and control samples of sea water, hand dug wells and boreholes (Appendix 3).

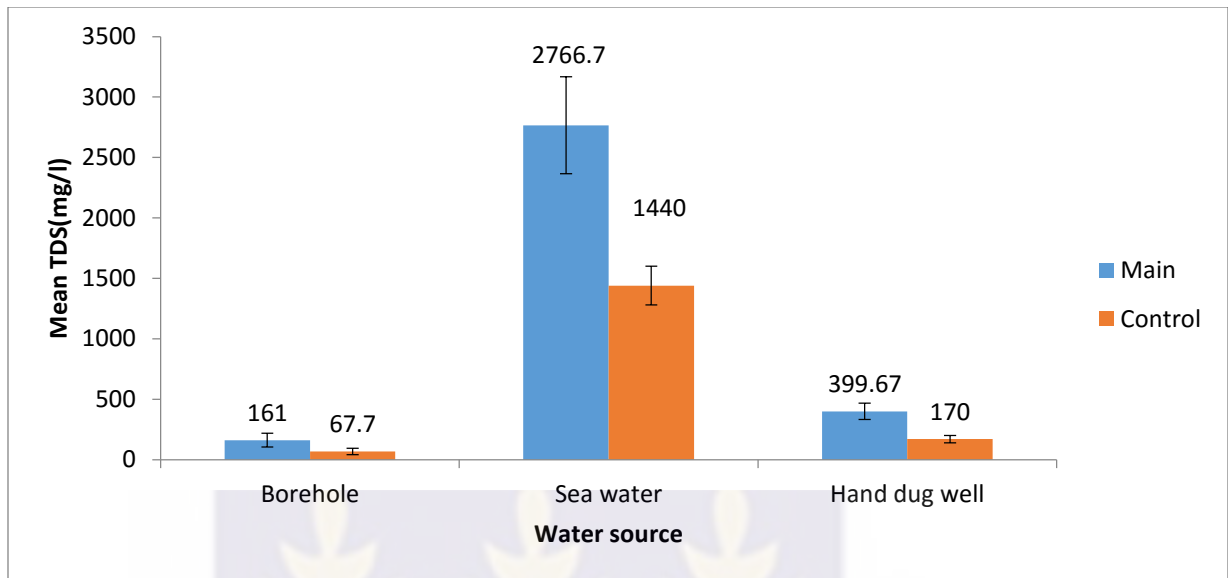


Figure 4. 6: Mean TDS of water samples from study sites

4.1.7 Turbidity

The mean turbidity of the test water samples ranged from a minimum of 0.64NTU (borehole) to a maximum of 12.1 mg/l (sea water) (Fig 4.7). The turbidity of the sea water for both the test samples and their corresponding control samples showed higher variations compared to that of borehole and hand dug wells. Analysis of variance at 95% confidence interval revealed statistically significant differences in turbidity among the water sources ($P \leq 0.05$) (Appendix 2). Bonferroni pair wise multiple comparisons, showed that there were no differences in turbidity between hand dug wells and boreholes but was significantly different from sea water (Appendix 3).

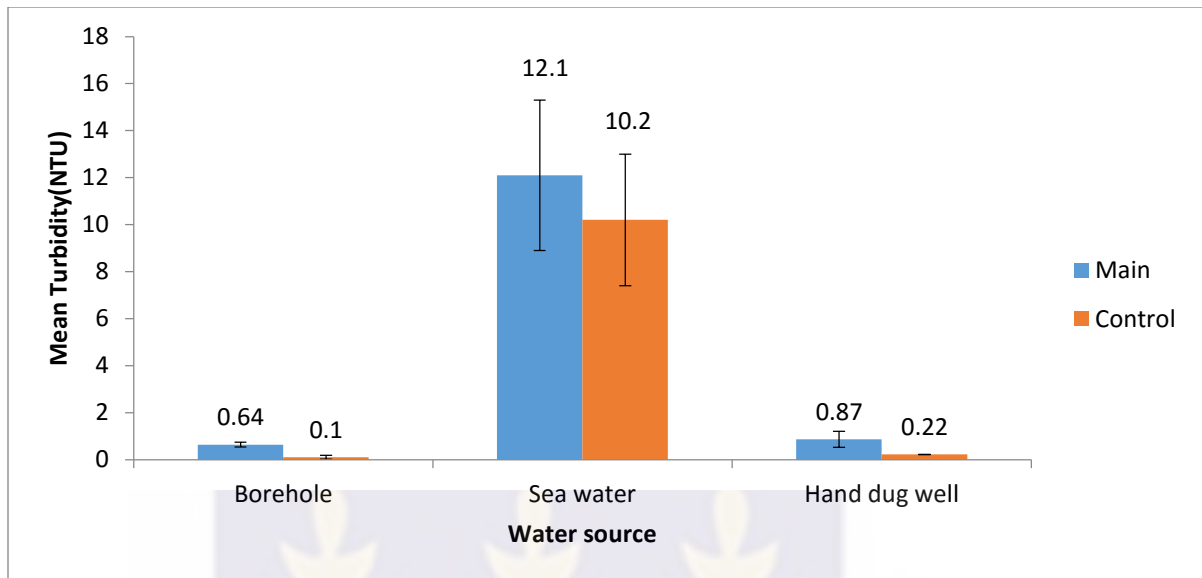


Figure 4.7: Mean Turbidity of water samples from study sites

4.1.8 Heavy metals

4.1.8.1 Nickel (Ni)

The mean Nickel levels of the test water samples ranged from a minimum of 0.44mg/l (hand dug well) to a maximum of 0.77 mg/l (sea water) (Fig 4.8). The nickel levels of the sea water for both the test sites and control sites showed higher variations compared to that of borehole and hand dug wells. Analysis of variance at 95% confidence interval revealed statistically significant differences in nickel levels among the water sources ($P \leq 0.05$) (Appendix 2). Bonferroni pair wise multiple comparisons, showed that there were no differences in nickel concentrations between hand dug wells and boreholes but was significantly different from sea water (Appendix 3).

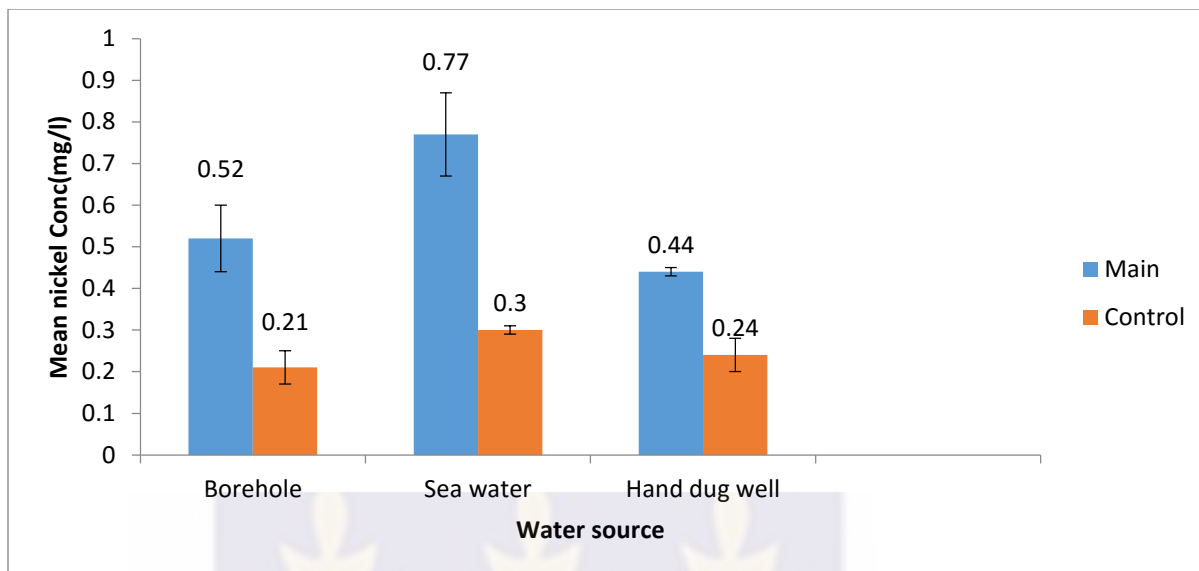


Figure 4. 8: Mean Nickel concentrations of water samples from study sites

4.1.8.2 Chromium (Cr)

The mean Cr levels of the test water samples ranged from a minimum of 0.07 mg/l (sea water) to a maximum of 0.12 mg/l (borehole) (Fig 4.9). The Cr levels of the test water samples for sea water, hand dug wells and borehole showed higher variations compared to that of their controls. Analysis of variance at 95% confidence interval did not show any statistically significant differences in Cr levels among the water sources ($P \leq 0.05$) (Appendix 2).

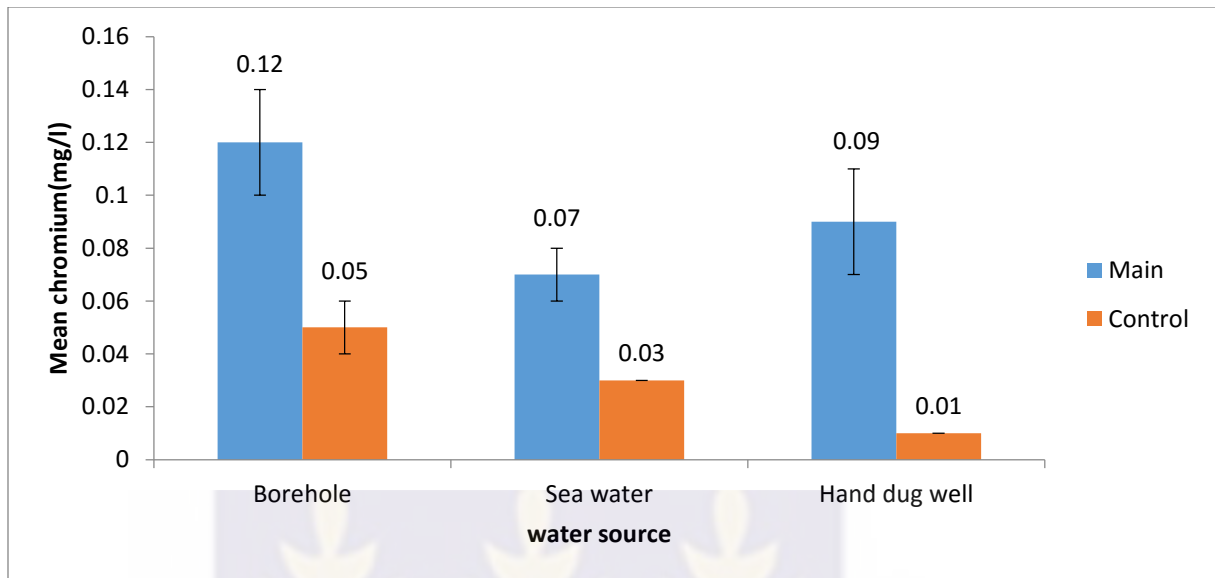


Figure 4. 9: Mean Chromium concentration of water samples from study sites

4.1.8.3 Iron (Fe)

The mean Fe concentrations of the test water samples ranged from a minimum of 0.31 mg/l (borehole) to a maximum of 64.54 mg/l (sea water) (Fig 4.10). The Fe concentrations of the test water sample for sea water and control showed higher variations in Fe concentrations compared to that of hand dug wells and boreholes. Analysis of variance at 95% confidence interval did not show any statistically significant differences in Fe concentrations among the water sources ($P \leq 0.05$) (Appendix 2).

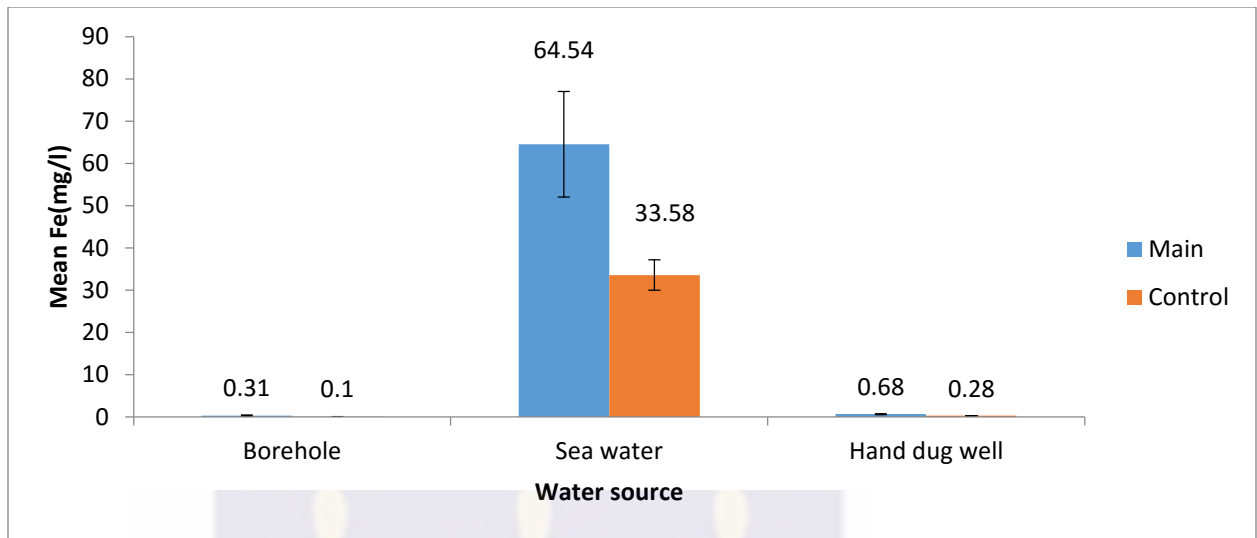


Figure 4.10: Mean Iron concentrations of water samples from study sites

4.2 Assessment of Impact of Oil and Gas on Fish Quality

4.2.1.1 Heavy metal in Fish sample

The heavy metal concentrations in the muscles and gills of two different species of fish, namely; *Pomatomus saltatrix* and *Cynoscion regalis* were determined. With the exception of Cd and Cr that were not detected in the two fish species studied, Pb, Cu and Fe however were detected at varying concentrations. The mean Pb levels in *Pomatomus saltatrix* fish species ranged from a minimum of 1.54-2.22ppm with a mean value of 1.86 ± 0.19 ppm, Fe levels ranged from 124.50-138.96ppm with mean value of 132.82 ± 4.31 ppm and Ni levels ranged from 1.45-2.2ppm with mean value of 1.95 ± 0.25 ppm. That of *Cynoscion regalis* also recorded Pb levels ranging from a minimum of 2.18-2.62ppm with a mean value of 2.44 ± 0.13 ppm, Fe levels ranged from 190-210ppm with mean value of 200.26 ± 5.72 and Ni levels ranged from 2.89-3.28ppm with mean value of 3.13 ± 0.12 ppm (Table 4.1).

Table 4.1: Concentration of heavy metals in fish species from study area.

Heavy Metal	Fish Species	Mean $\pm$ SD	Min.	Max.
Lead	<i>Pomatomus</i>	1.86 $\pm$ 0.19	1.54	2.22
	<i>saltatrix</i>			
	<i>Cynoscion</i>	2.44 $\pm$ 0.13	2.18	2.62
	<i>regalis</i>			
Cadmium	<i>Pomatomus</i>	(ND)	0.00	0.00
	<i>saltatrix</i>			
	<i>Cynoscion</i>	(ND)	0.00	0.00
	<i>regalis</i>			
Chromium	<i>Pomatomus</i>	(ND)	0.00	0.00
	<i>saltatrix</i>			
	<i>Cynoscion</i>	ND	0.00	0.00
	<i>regalis</i>			
Nickel	<i>Pomatomus</i>	1.95 $\pm$ 0.25	1.45	2.24
	<i>saltatrix</i>			
	<i>Cynoscion</i>	3.13 $\pm$ 0.12	2.89	3.28
	<i>regalis</i>			
Iron	<i>Pomatomus</i>	132.82 $\pm$ 4.31	124.50	138.96
	<i>Saltatrix</i>			
<i>Cynoscion</i>	<i>Regalis</i>	200.26 $\pm$ 5.77	190.00	210.00

ND-not detected

When the student t-test statistics was used to determine whether statistically significant differences exist in concentrations of heavy metals between the two fish species, the results showed that, there was a significant differences in Fe, Ni and Pb concentrations between the two fish species at 95% confidence level ($P \leq 0.05$)(table 4.2).

Table 4. 2: showing student t – test analysis of heavy metals in fish samples from study area

One – sample test (test value 1)

	t-value	df	p-value	Mean difference	95 % Confidence level	
					Lower	Upper
Lead	6.854	5	0.001*	1.15000	0.72	1.58
Nickel	5.260	5	0.003*	1.54333	0.79	2.29
Iron	10.734	5	0.000*	165.5433	125.89	205.19

***Significant ($P \leq 0.05$).**

4.3 Assessment of Impact of Oil and Gas on Soil Quality

4.3.1.1 Analysis on physico-chemical parameters of soil

The soil quality parameters in soil samples of two communities each from Jomoro, Ellembele and Ahanta West close to the oil and gas fields were determined to ascertain direct and indirect impact of oil and gas. The results showed the mean pH of soil ranging

from $6.53 \pm 0.26 \text{ mg/kg}$ at Jomoro sampling sites to a maximum of $7.47 \pm 0.18 \text{ mg/kg}$ at Ellembelle sampling sites. The conductivity of the soil samples ranged from $161.33 \pm 3.21 \text{ mg/kg}$ at Jomoro sampling site to a maximum of $1951 \pm 30.51 \text{ mg/kg}$ at Ahanta West sampling site. The conductivity of the soil sample ranged from $161.33 \pm 3.21 \text{ mg/kg}$ at Jomoro sampling site to a maximum of $1951 \pm 30.51 \text{ mg/kg}$ at Ahanta West sampling site. The Cation Exchange Capacity (CEC) also ranged from a minimum of $1.62 \pm 0.032 \text{ mg/kg}$ at Ellembelle sampling site to a maximum of $7.31 \pm 0.44 \text{ mg/kg}$ at Ahanta West sampling site and the organic carbon ranged from $0.83.3 \pm 0.002 \text{ mg/kg}$ at Ellembelle sampling site to a maximum of $1.71 \pm 0.06 \text{ mg/kg}$ at Ahanta West sampling site (Table 4.3). Analysis of variance at 95% confidence level revealed statistically significant differences in pH, conductivity, cation exchange capacity and organic carbon levels among the sampling site ($P \leq 0.05$) (Table 4.3).

Table 4. 3: Descriptive statistics of soil quality parameters at sampling site

Descriptive				
Parameter/Districts		Mean $\pm$ SD	Min	Max
pH	Jomoro	6.53 ± 0.26	6.48	6.57
	Ellembelle	7.47 ± 0.18	7.25	7.84
	Ahanta West	7.34 ± 0.70	7.20	7.42

Conductivity	Jomoro	1818.67 ± 35.87	1768.00	1888.00
	Ellembelle	161.33 ± 3.21	159.00	165.00
	Ahanta West	1951.00 ± 30.51	1890.00	1983.00
Cation	Jomoro	4.41 ± 0.31	4.25	4.66
Exchange	Ellembelle	1.62 ± 0.032	1.56	1.67
Capacity	Ahanta West	7.31 ± 0.44	7.25	7.40
Organic Carbon	Jomoro	1.21 ± 0.006	1.20	1.22
	Ellembelle	0.83 ± 0.002	0.78	0.86
	Ahanta West	1.71 ± 0.006	1.70	1.72

4.3.1.2 *Correlation between soil quality parameters*

To investigate the association, the direction and strength of the soil quality parameters, Pearson's Product Moment Correlation Coefficient (PPMC) was used. Considerable numbers of significant positive correlation were observed between the following

variables; CEC and conductivity ($r=0.891$, $P<0.01$), organic carbon and conductivity ($r=0.859$, $P<0.05$), organic carbon and CEC ($r=0.996$, $P < 0.01$) (Table 4.4).

Table 4.4: Karl Pearson's moment correlation analysis on some soil quality parameters

Parameters		pH	Conductivity	Cation exchange capacity	Organic carbon
pH	Pearson Correlation	1			
	Sig. (2-tailed)				
	N	9			
Conductivity	Pearson Correlation	-.507	1		
	Sig. (2-tailed)	.163			
	N	9	9		
Cation exchange capacity	Pearson Correlation	-.105	0.891**	1	
	Sig. (2-tailed)	.788	0.001		
	N	9	9	9	
organic carbon	Pearson Correlation	-.034	0.859*	0.996**	1
	Sig. (2-tailed)	.931	.003	0.000	
	N	9	9	9	9

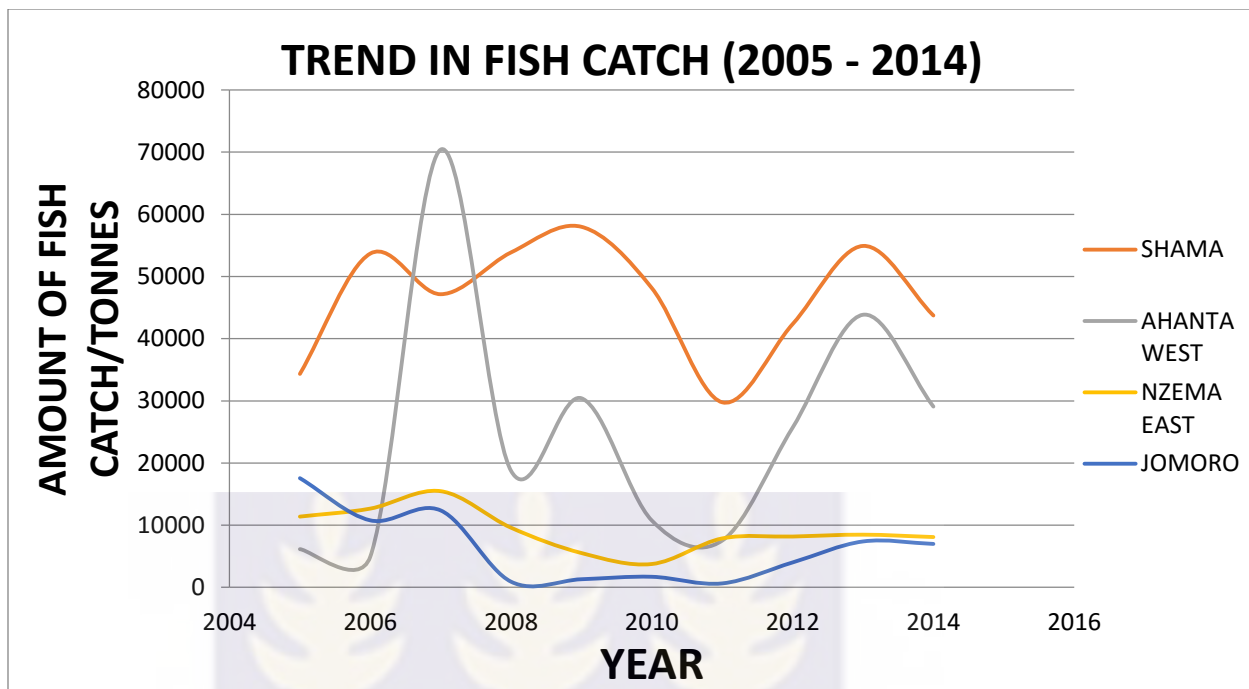
** Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed).

4.4 Assessment of the trend of fish catch between 2005 and 2014 in the enclave

Figure 4.11 shows the trend of fish catch in the study area with a comparison made between four (4) out of the six (6) coastal districts in the oil and gas enclave. The districts included; Jomoro, Nzema East, Ahanta West and Shama. The Ellembele was replaced with Nzema East due to lack of catch data for analysis according to the Fisheries Commission's Department, Western Region.

The Fig. 4.11 reveals that the Jomoro district lies very low from year 2008 to 2014 although it recorded appreciable levels before year 2008 at almost 20,000 tonnes per year of fish catch. The Nzema East district also recorded higher levels of fish catch before 2007 when exploration had not started with a sharp decrease from 2008 to 2011. The Ahanta West district shows an undulating trend in fish catch with a maximum level of 70,000 tonnes per year in around 2007 and a minimum of 7,000 tonnes per year in somewhere 2011. The Shama district however, portrays a consistent trend in fish catch almost throughout the ten year period with a least amount of catch of 30,000 tonnes per year in 2011.



Source of Data: Fisheries Commission, Western Region.

Figure 4. 11: A graph showing trends of fish catch against years in the study area

Plate 4.1 below confirms the fact of low fish catch by fishermen after a search for fish in the Jomoro district. At the far end of the fishing net is a heap of sea weed (*Sargarssum* spp.) from which fish have to be sorted out.



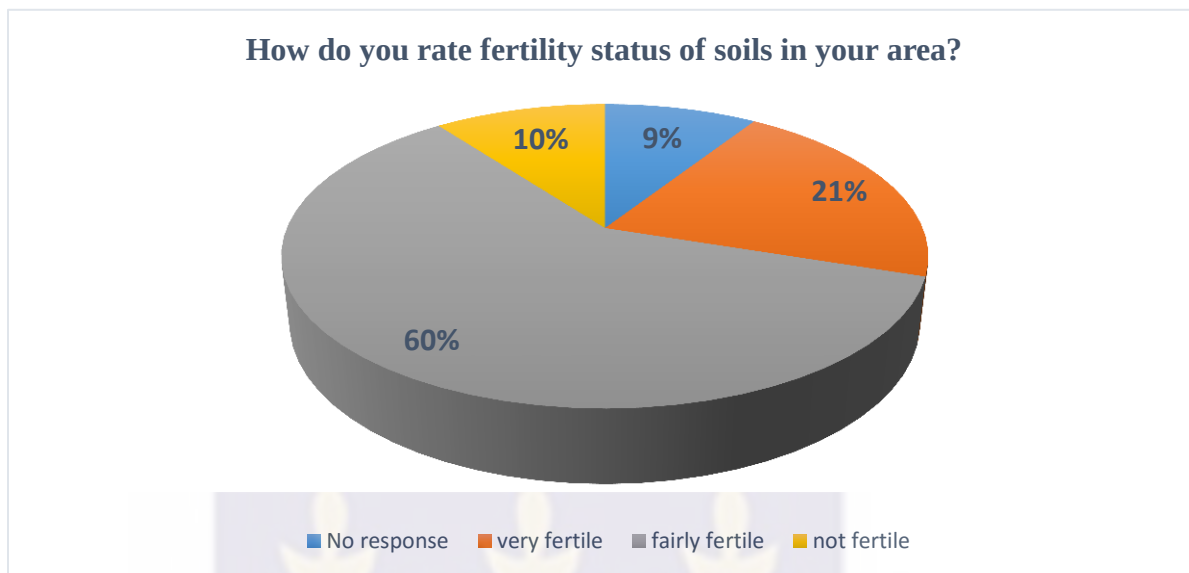


Figure 4. 12: Respondents views on fertility status of soils in the study area.

With reference to figure 4.13, Out of the total number of 263 questionnaires retrieved from respondents, 236 representing 90% claimed emphatically that the amount of fish catch 10 years ago was very good with 21 representing (8%) indicating a good catch. Only 3 of the respondents representing 1% answered satisfactory without any response for poor catch.

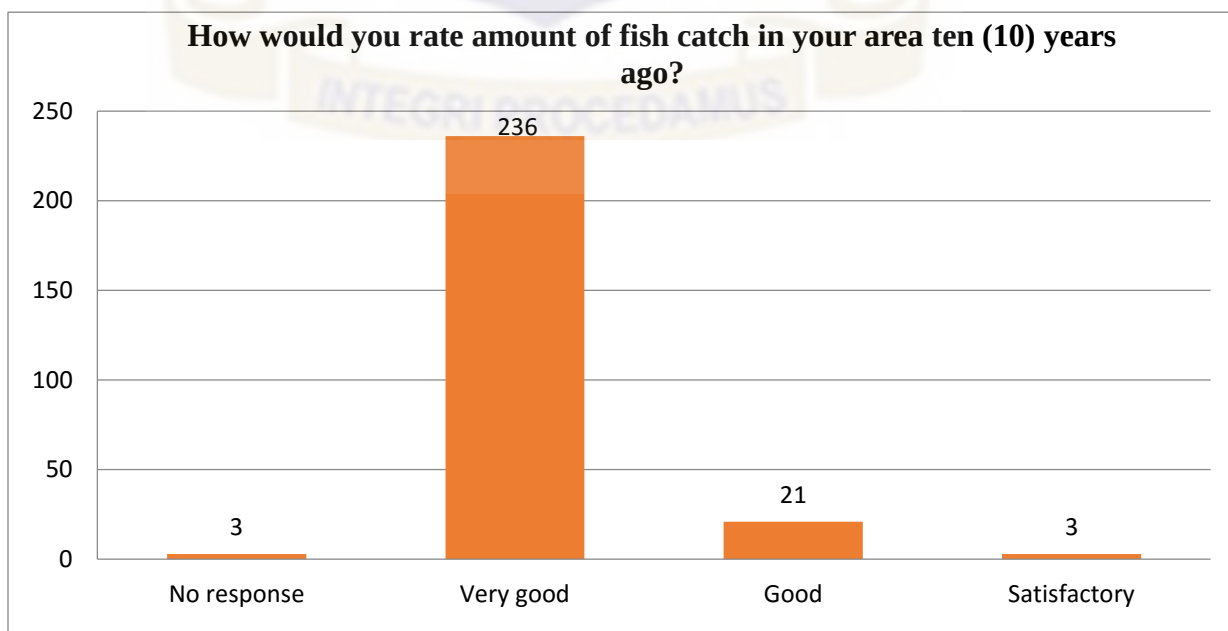


Figure 4.13: Respondents views on amounts of fish catch 10 years ago in the study area

Figure 4.14. Shows respondents' views on the amount of fish catch from year 2014 up to 2017. The majority of 195 (74%) indicated "poor" with only 4 of the respondents representing 1.5% claiming to have a very good catch. The number of respondents satisfied with the catch levels was also 57 representing about 22%.

As depicted in plate 4.2, the amount of fish obtained by the fishermen is woefully not up to expectation. The catch constitutes virtually of sea weeds thus rendering the efforts on fishing highly unfruitful.

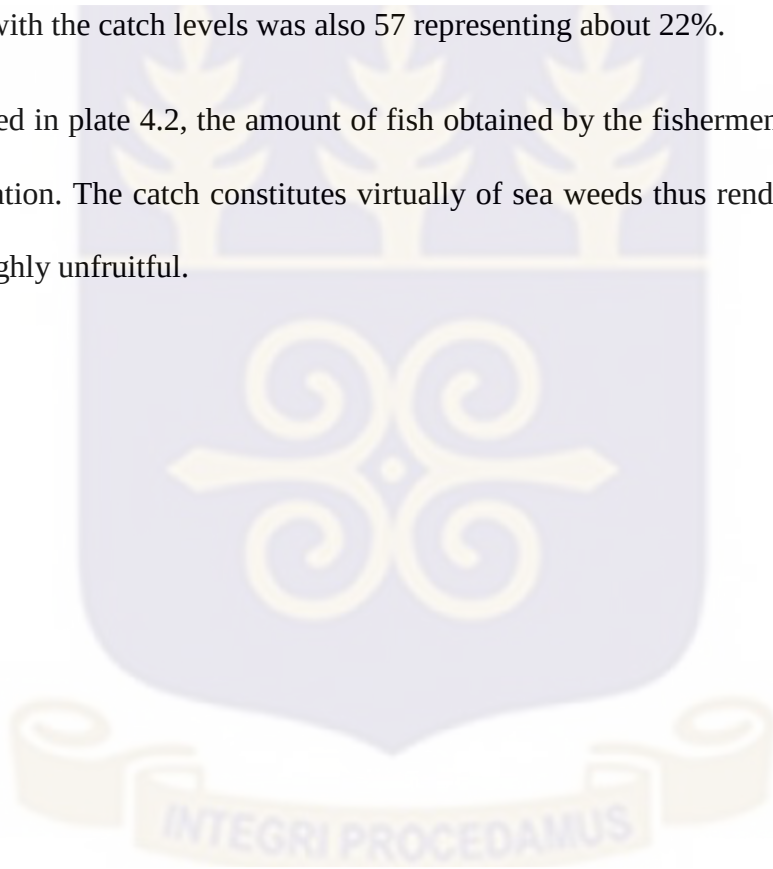




Figure 4.15 shows respondents' views on the cause of low fish catch levels with 212 indicating oil and gas activities representing about 81%. Other factors as part of respondents claim were fishing method and climate change with 43 and 1 respondent respectively.

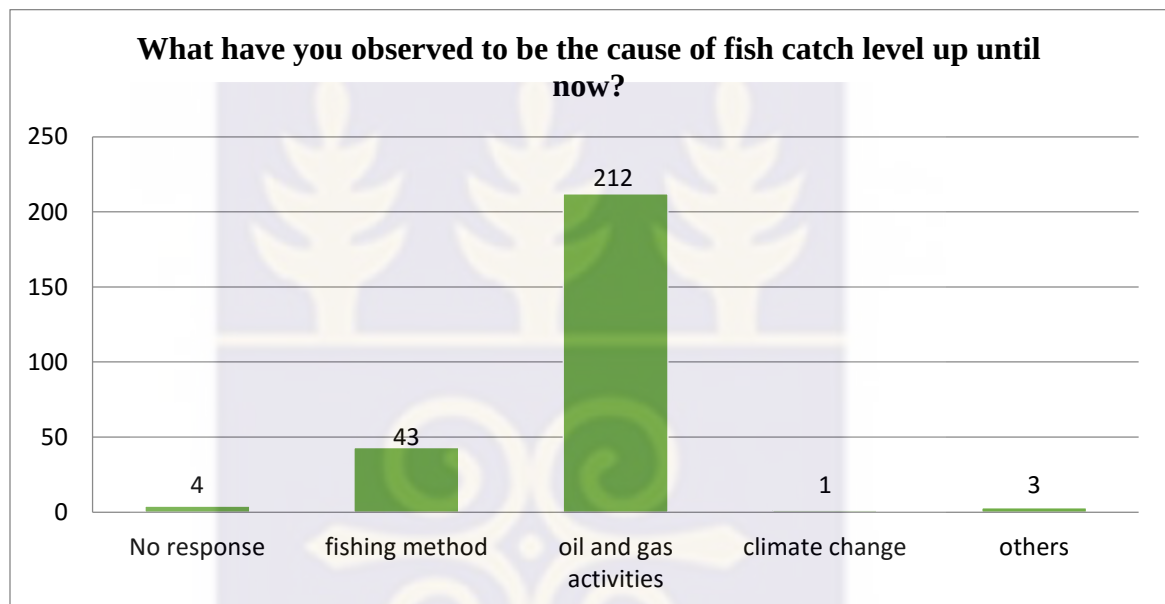


Figure 4.15: Respondents views on observed cause of fish catch levels up until now.

Figure 4.16 shows respondents views on experiences of mortality of fish and other marine organisms with 61% indicating "yes". Respondents without any experience on mortality were 32%. However, 7% of the respondents had no answer for observed cause of mortality.

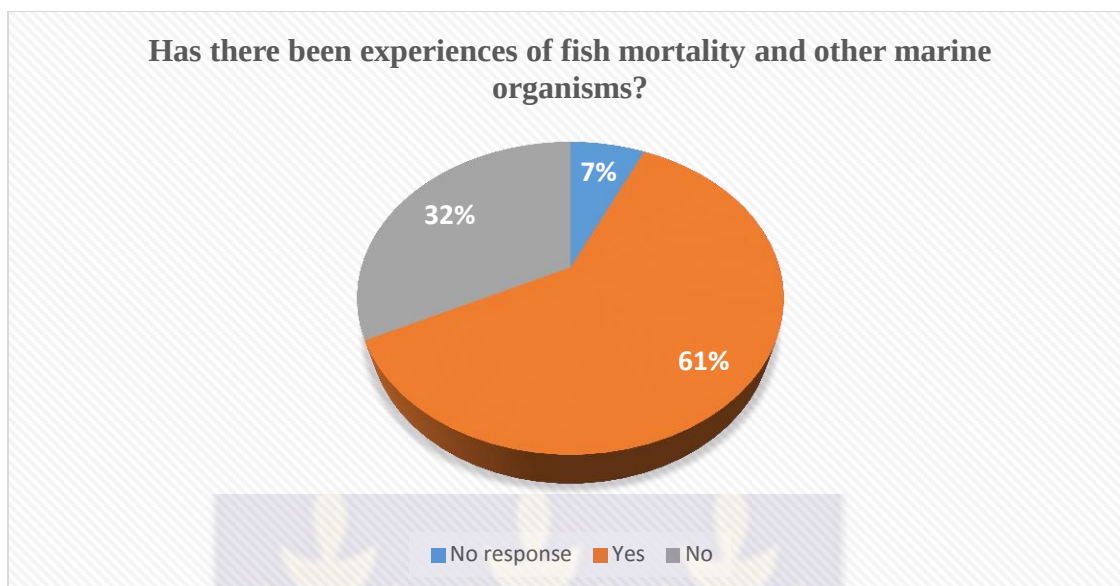


Figure 4.16: Respondents views on mortality of fish and other marine organisms

Figure 4.17 shows respondents opinion on the cause of mortality of marine organisms in the study area. The number of respondents who attributed cause of mortality to oil and gas activities were 136 representing 52% whiles 106 respondents had no response to the question. The rest of the respondents associated the death of marine organisms to the influx of foreign vessels with propellers and other factors not known to them.

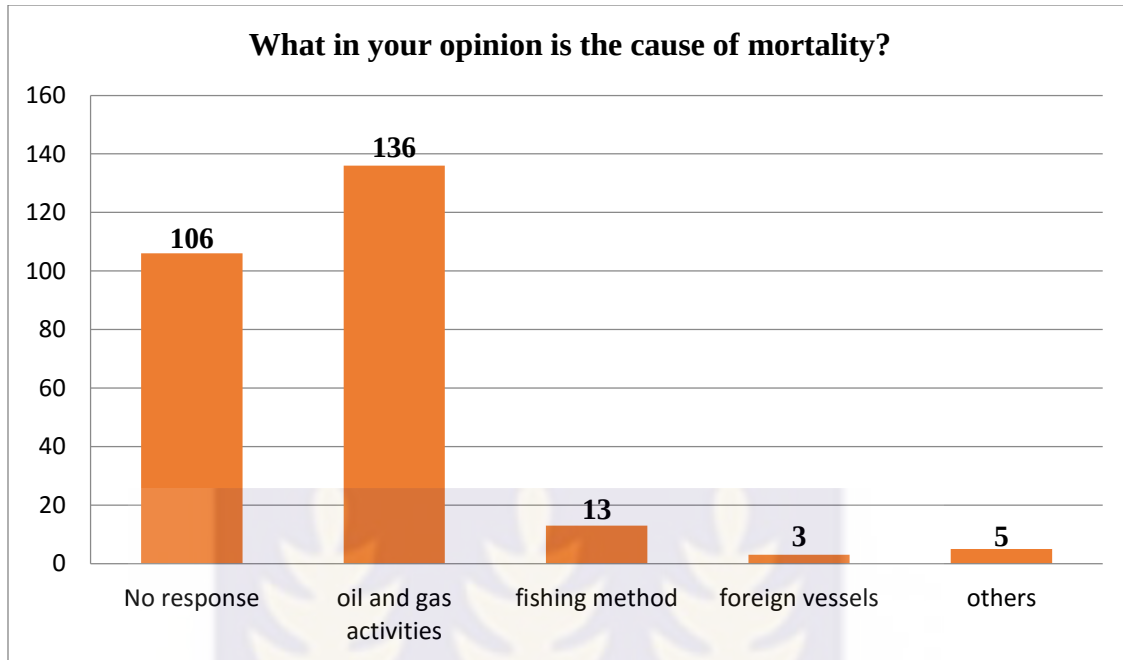


Figure 4.17: Respondents opinion on cause of mortality of marine organisms.

Figure 4.18 shows respondents views on the quality of fish they consume. The majority of 65% of them answered with affirmation whiles 27% were not satisfied with the quality of fish obtained from the sea and surrounding water bodies. The rest of the respondents of 8% gave no response to the question.

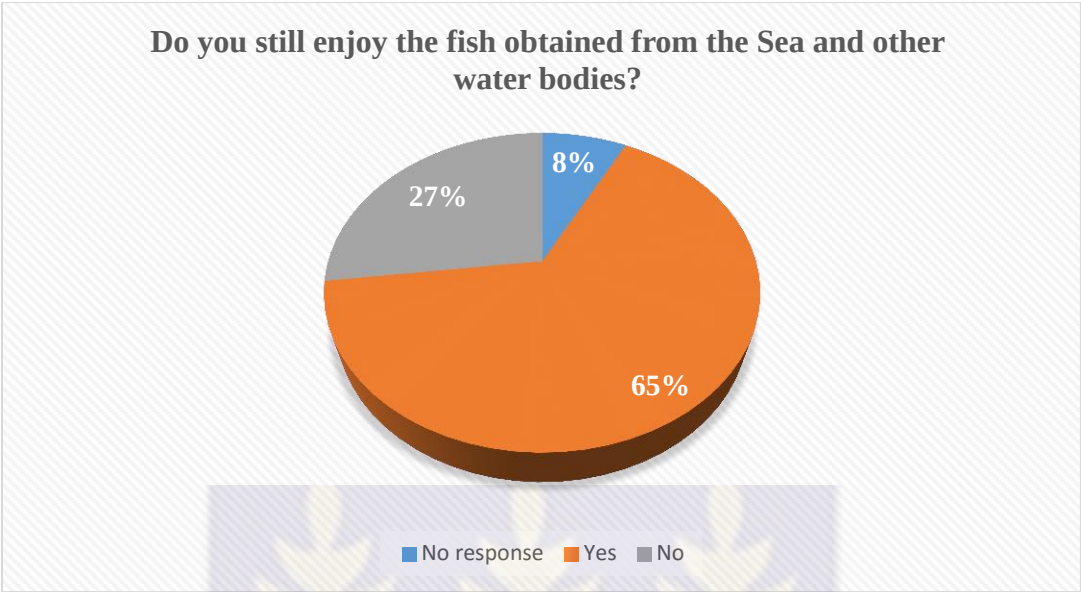


Figure 4.18: Respondents views on quality of fish from the Sea and Water bodies

Figure 4.19 shows respondents views on major benefits obtained from the oil and gas production as residents. A majority of 51% gave no response to the question with 31% indicating there has been no benefit at all. However, 12% and 6% of the respondents claimed to have gained scholarships and social amenities respectively.

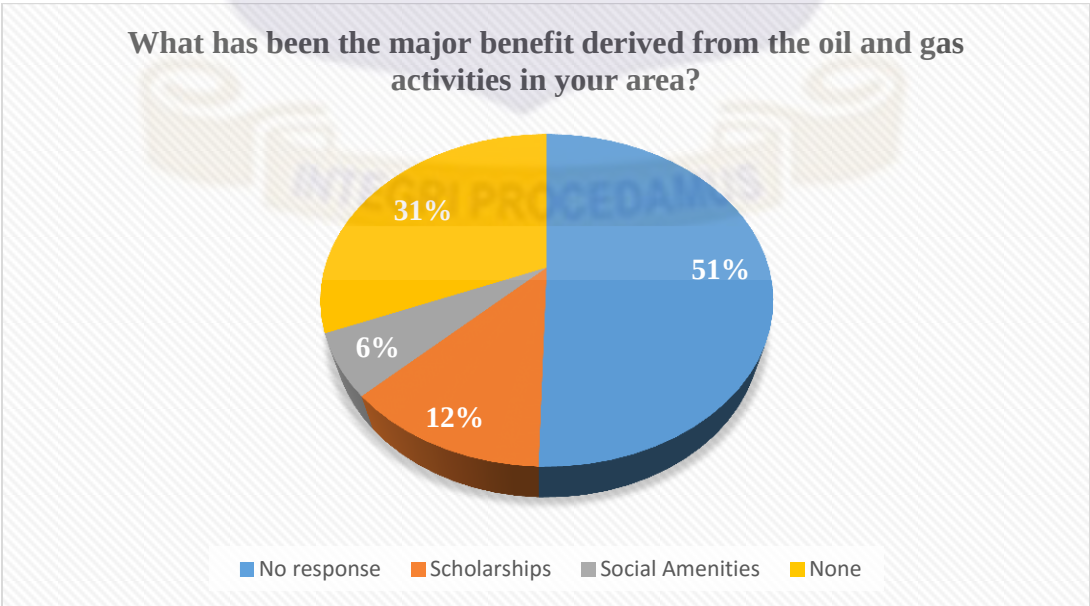


Figure 4.19: Respondents views on benefits from oil and gas activities in the area.

Figure 4.20 shows respondents views on whether benefits obtained are from the Government or oil company. The very few constituting only 9% indicated to have had their benefit from the Government whiles 13% had it from oil and gas companies or partners. However, the majority of 78% gave no response to the question.

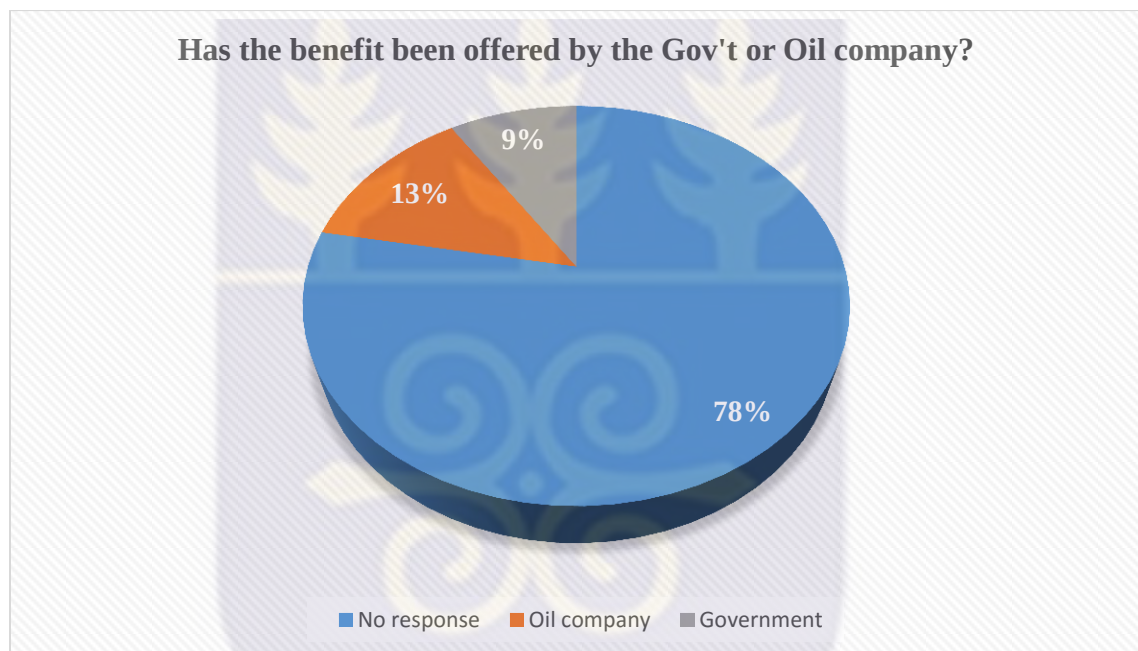


Figure 4.20: Respondents views on whether benefit is offered by Government or Oil company.

Figure 4.21 shows respondents views on whether the sale of fish in their communities is still lucrative and to their expectation. Most of the respondents answered "No" to the question whiles only 7% responded in the affirmative. However, 36% gave no response to the question.

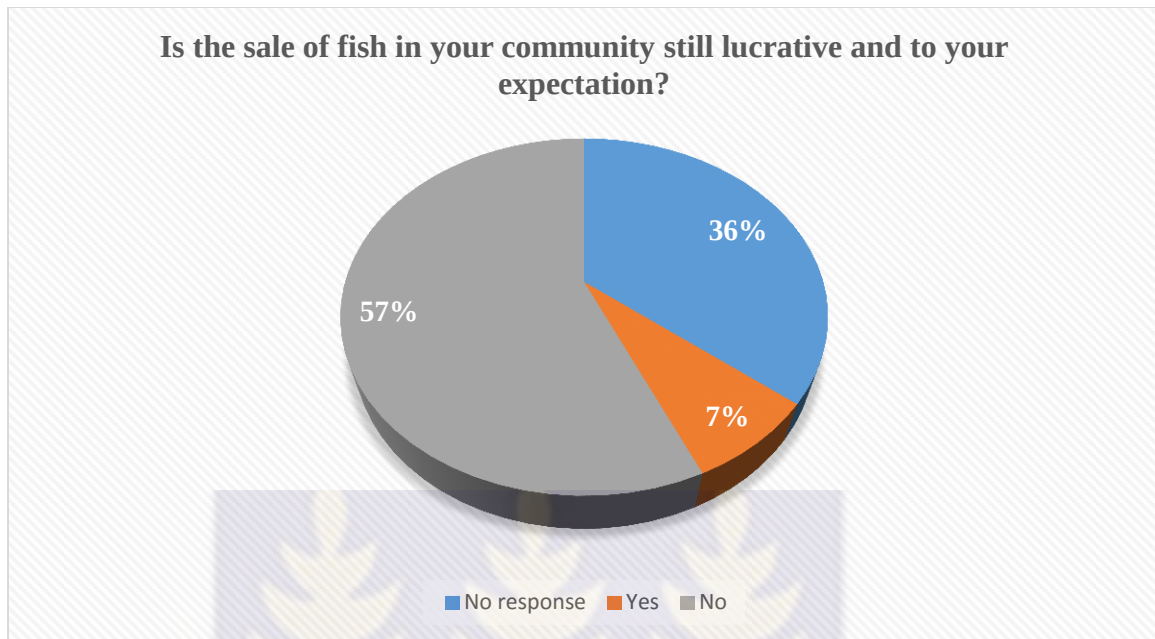


Figure 4.21: Respondents views on whether sale of fish is lucrative or not

4.6 Public perception on effects of oil and gas on beaches and shoreline recreation.

The study ascertained whether demographic characteristic of respondents (Table: 4.5), are significantly associated with perception on the effects of oil and gas on beaches and shorelines recreation in the enclave. The study revealed that gender was significantly associated with the perception ($\chi^2 = 21.39$, $P = 0.001$). Educational background of respondents was found also to be significantly associated with perception ($\chi^2 = 36.09$, $P = 0.001$). However, there was no significant association between marital status and duration of stay in the locality to perception in the bivariate analysis at 95% confidence level (Table 4.6).

Table 4.5: shows details of demographic characteristics of respondents in the study area based on gender, age, marital status and educational background. The others are occupation and the duration of stay in a locality. Most respondents had their occupation to be fishing as reflected in gender with majority being males. The majority of 97% of respondents had stayed in their locality for more than ten (10) years with MLSC/JHS being the educational background of most respondents.

Table 4. 5: Demographic characteristics of respondents

Variables	Frequency	Percentage (%)
Gender		
Male	188	71.5
Female	75	28.5
Total	263	100
Age		
20-29	37	14.0
30-39	86	32.6
40-49	83	31.5
50-59	36	13.6
60-69	12	5.0
70-79	8	3.0
80-89	1	0.3
Total	263	100

Marital Status		
Married	202	76.8
Single	32	12.2
Separated	22	8.4
Divorced	7	2.6
Total	263	100
Educational Qualification		
None	24	9.1
Primary	59	22.4
MSLC/JHS	150	57.0
SHS	17	6.5
Tertiary	13	5.0
Total	263	100
Occupation		
Fishermen	104	40.0
Farmer	65	25.0
Trader	50	19.0
Public Servant	14	5.3
Student	6	2.3
Self Employed	24	9.1
Total	263	100

	Below 5yrs.	3	1.0
Duration of	5 - 10 yrs.	5	2.0
Stay	Above 10yrs.	255	97.0
	Total	263	100

Source: *Field Survey, 2017*

The findings revealed that gender, educational level and duration of stay in the community significantly influenced expectations of respondents upon visiting the beaches and shoreline ($P \leq 0.05$). Marital status of respondents however, was found not to be significantly associated with expectations of respondents upon visiting the beaches and shoreline at 95% confidence level ($P \geq 0.05$)(Table 4.6).

Table 4. 6: Chi – square test analysis on respondent perception on effects of oil and gas activities on beaches and shoreline recreation in study area.

Variable	F(%), n=263	χ^2	P-value
Gender		21.39	0.001*
Male	164(62.4)		
Female	63(37.6)		
Total	227(100%)		
Educational level			
No formal education	21(7.98%)	36.09	0.000*
Some formal education	206(78.33%)		
Total	227(100%)		
Marital status		13.59	0.093

Single	57(21.67%)		
Married	166(63.12%)		
Total	223(100%)		
Duration of stay in locality		27.92	0.06
>5yrs	2(0.76%)		
5-10yrs	4(1.52%)		
>10yrs	85(32.32%)		
Total	91(100%)		
*Significant (P<0.05)			

Table 4.7: Chi – Square test analysis on expectations of respondents upon visiting the beaches and shoreline.

Are expectations met upon visiting the beaches and shoreline			
Variable	F(%, n=263)	χ^2	P-value
Gender		26.41	0.001*
Male	54(20.53%)		
Female	33(12.5%)		
Total	87		
Educational level			
No formal education	16(6.08%)	53.22	0.000*
Some formal education	71(26.99%)		
Total	87		
Marital status		18.83	0.08
Single	25(9.5%)		
Married	60(22.8%)		
Total	85		

Duration of stay in locality		47.7	0.00*
>5yrs	3(1.1%)		
5-10yrs	1(0.38%)		
>10yrs	222(84.4%)		
Total	226		
*Significant (P<0.05)			





CHAPTER FIVE

5.0 DISCUSSION

The borehole test water sample recorded a mean pH value of 6.1 which was below the recommended limit. Besides, all other water samples fell within the WHO range for surface and ground water systems of 6.5-8.5. The results obtained indicated neutral to alkaline conditions and this may arise due to the bedrock of the area. The bedrock may be rich in limestone and sandstone which contains higher levels of carbonate and bicarbonates ions. These ions have high buffering capacity and can resist acidity, therefore may have accounted for the high pH levels recorded for the period. The mildly acidic pH levels recorded in the test borehole sample might be due to the dissolution of carbon dioxide from the atmosphere during water withdrawal or the presence of high level of organic matter within the soil zones whose oxidation releases carbon dioxide that reacts with water to produce a weak carbonic acid (Alakpodia, 1995). This was further confirmed by the Bonferroni pair wise multiple comparisons used to separate the means. It showed statistically significant differences in pH among test and control samples of water (Appendix 3).

The conductivity recorded for borehole and hand dug wells for both test and control water samples exceeded the WHO recommended limit of 250mg/l for drinking water. However, the fact that the test samples recorded higher conductivity values than the control is an indication that anthropogenic factors may be at play and could be attributed to direct pollution from the oil fields such as produced water discharge and drilling fluids. Oil and gas installations come with discharges such as produced water, process water, sewerage, sanitary and domestic waste, spills and leakages (E&P Forum/UNEP, 1997).

The idle fishermen desperate for livelihood alternatives now engage in commercial motor riding from one community to another which comes with dirty engine oil. Others are sale of agro-chemicals, metal scraps and general inputs for building construction.

Based on the WHO recommended guideline for TDS, water with a TDS less than 1000mg/l and 30,000mg/l for drinking water and saline water respectively is acceptable. However, the mean values for TDS for test samples were higher than the controls which also suggest a measure of higher turbidity. It is an indication of pollution from direct and indirect point sources and the effects it is likely to have on the marine ecosystem.

The mean values of BOD were high compared with the controls. This also indicates a high measure of organic matter contamination in test samples. Generally, a higher BOD in a sample translates into a lower DO. In Fishes, an average of 5 mg/l of dissolved oxygen (DO) is required for them to survive (Diaz et al., 2014). Thus decreased levels of DO may result in fish kills and stressful experiences by fish and other organisms. Factors that affect DO levels in natural water include presence of oxidisable substances, salinity, turbulence, temperature, and pressure (Lloyd 1992). Amongst these factors may be contributing to the high Biological Oxygen Demand with its replica effect on the amount of Dissolved Oxygen and the survival of marine organisms.

The mean levels of heavy metals in water, Nickel and Chromium levels were low compared to quality guidelines in Ghana of 0.5. However, these metals had values higher than the control samples. This may be an indication of change in the environment due to precursors such as heavy metals as may be associated with the oil and gas activities. Iron with a permissible level of 10mg/l had a mean value far above that of the control sample. Such high levels of iron may be linked with acid mine drainage and acid deposition/rain.

Organic substances which form a major part of crude oil and petroleum products may to a large extent increase the heavy metal concentration upon release into water bodies. Smaller amounts of heavy metals such as lead (Pb), Cadmium (Cd), Mercury (Hg), Chromium (Cr), Cobalt (Co), Iron (Fe) and Copper (Cu) above recommended levels are known to affect humans and the aquatic ecosystem (Ademoroti, 1996). According to Ademoroti, (1996) and (Bowen 1979), traces of heavy metals such as chromium, lead, iron and mercury above stipulated levels are toxic to aquatic ecosystems and human well-being. Neff (2000) also revealed that produced water for ocean discharge contains up to 48 parts per million (ppm) of petroleum, because it usually has contact with crude oil in the reservoir rocks.

The analysis of heavy metals in fish samples found Pb, Ni and Fe to be present in fish species sampled and exceeded the recommended limit set by the European Union (EU). As stated earlier, the samples of fish were collected based on proximity to the oil and gas fields. The *Pomatomus saltatrix* (Blue fish) were sampled from the Shama district 210 km west of the oil fields while the *Cynoscion regalis* (Weak fish) were from the Jomoro and Ellembelle districts which are 60 km away from the fields. The higher mean values of heavy metals in the weak fish could possibly be an indication of prevalence from the sampling site in the Jomoro district as compared to the Blue fish from the Shama sampling sites. It was confirmed by the student t-test analysis which showed significant differences in Pb, Ni and Fe concentrations in the fish species at 0.05 confident level.

According to Burger et al., (2002), there are two main routes of heavy metals exposure. The primary route of intake of these metals is through the gills or transport of dissolved contaminants in water across biological membranes and ionic exchange. The secondary

route is through ingestion of food or sediment particles with subsequent transport across the gut. The aquatic micro flora or micro fauna which constitute the food chain for fish species accumulate these metals in their living cells from the environment. The fish consume them and gradually get enriched with heavy metals through bioaccumulation which may subsequently affect humans on the food chain. These metals are known to produce adverse effects on aquatic biota and human health (Akan, 2012). However, as revealed by Yang et al., (2010), fish have been reported to be very much sensitive to Pb and its uptake increases with increasing concentration in the environment. Fish living in contaminated sediment showed higher concentration of Pb in gills and muscles of fish also in a study by Abarshi et al., (2017) which is in consistent with the findings of this study. Beyer et al. (2000) postulates that "Cr at sublethal concentrations in fish mainly accumulates in gills and liver". The effects of these metals in fish include reduction of growth and reproductive capacity. The increase in contamination of metals in fish may be due to metal contaminated diet which may come from discharge of oil residue and produced water which contains high levels of heavy metals (Forstner et al., 2012).

The study found a strong negative correlation between pH and Conductivity, a negative correlation between pH and CEC and also pH and Organic Carbon. However, there was a positive correlation existing between Conductivity and CEC, Conductivity and Organic Carbon and also Organic Carbon and CEC. Cation exchange capacity is the total capacity of a soil to hold exchangeable cations. It influences a soils ability to hold unto essential nutrients to be able to provide a buffer against soil acidification. Thus, organic matter and soils with a higher clay fraction have higher CEC. Thus, sandy soils rely heavily on the high CEC of organic matter for retention of nutrients in the topsoil. According to Osuji

and Nwoye (2007), cation exchange capacity is a very important soil property that influences soil structure, nutrient availability, soil pH and soil reaction to fertilizers. The negative correlation between pH and CEC therefore suggest a low cation exchange capacity of soils as pH recorded were generally high. This establishes the fact that coarse sandy soil in the study area lacks the capacity to hold essential nutrients for plants growth. It also confirms the views of the respondents that soils in the area are fairly fertile. However, the fair fertility of soil may not be blamed on oil and gas activity as established by Atuma and Oje (2013), that organic matter and total nitrogen decline were consistent with increasing distance from oil fields to hamper formation processes in soil.

With regards to the trend of fish catch in the study, the results suggested that the Jomoro district had a vast and great reduction in catch levels although it showed some appreciable or improvement in years 2005, 2006 and 2007 which were before the intensive oil activity (See Fig. 4.11). It is the part of the study area 60km from the oil fields and may therefore be attributed to the effects of smothering by oil residue deposited unto the sea bed which affect spawning, nursing and feeding habits of fishes (Samiullah, 1985).

The same can be said about the Nzema East district with a gradual reduction from 2008 throughout the years up to 2014. Its 2009 and 2010 amounts of fish catch recorded were the poorest amongst all the years in focus. This could be expected as the period marked the beginning of intensive oil production in Ghana. The Ahanta West District had its worse performance in 2010 and 2011 although there was a great boost in 2007 which may be attributed to exploratory activities with massive seafloor perturbation then before production started. Thus, the commencement of intensive oil and gas production is linked

with the dwindling effect on amount of fish catch in the area. According to Demeke and Tassew (2017), the response of fish to oil and gas residues in water is highly associated with loss of movement, coordination and death of organisms. Generally, the Ahanta West and Shama Districts seem to have achieved consistent catch levels during the period with catch in Shama being very stable. The consistency in fish catch from such districts can however, be linked to their far distances of about 200 km to the Jubilee Fields. The other oilfields, which on the other hand are closer to the Jubilee Fields are Jomoro, Nzema East and even parts of Ahanta West (Cape Three Points) being a probable source of the inconsistency in fish catch.

On the public perception of oil and gas impact on ecosystem services and human livelihoods, the survey revealed diverse opinions from the respondents. For instance, the fertility of soil was said to be fair based on crop harvest respondents obtain from their farmlands. According to Jobson et al. (1974), the alteration of carbon - nitrogen ratio by oil residue leads to nitrogen deficiency and threatens the survival of soil biota. Besides, the oil and gas exploration and production in the area has led to varying forms of soil degradation due to onshore installations. The amount of fish catch before the oil production ten (10) years ago in the study area as established by the survey conducted was very good which according to respondents met their needs. However after an intensive oil and gas activity, the amount of fish catch as expressed in the survey is very poor. Such a drastic change in fish catch may therefore be attributed to oil exploration impact as a major factor of ecosystem variation (World Rainforest Movement Bulletin, 2009). Moreover, the survey revealed mortality experiences of fish and other marine organisms to be high with most respondents associating it to the production of oil and gas

offshore (Anon, 2010). The quality of fish in terms of taste was suitable to respondents as revealed in the survey but its sale by the fisher folk was indicated as not lucrative at all due to the dwindling levels of fish catch recorded by fishermen. The survey also confirmed that respondents have not benefited from the oil and gas production as residents in the enclave whose surroundings are being exploited. This has brought to the fore absolute disgust and disappointment in the minds of respondents which reflected in their reception towards the survey team.

The study also sought to ascertain public perception on effects of oil and gas on beaches and shoreline recreation. From the analysis of results, gender was found to be significantly associated with public perceptions. Thus, gender influenced how respondents perceive oil and gas impact on beach and shoreline recreation. Based on the social survey, there was 71.5% of males which establishes the fact that the males believed the oil and gas industry has effect on beach and shoreline recreation. The educational background of respondents was also found to highly influence perceptions of respondents. Thus 91% of respondents perceived the oil and gas activity had impact on beach and shoreline recreation. However, the marital status and duration of stay in locality had no relationship with respondent's perception and oil and gas effects on beach and shoreline recreation (See Fig. 4.5).

Again from the results, some demographic characteristics were noticed to influence the expectations of respondents upon visit to the beaches and shoreline. Gender, educational level and duration of stay in locality were identified to influence respondent's expectations. This meant that, males, those with formal education and those who had stayed in the area over 10 years that oil and gas activity were categories that determined

expectation at the beaches and shoreline. Nevertheless, the marital status of respondents was found to have no influence on expectations of visits to the beach and shoreline. This was probably due to the fact that marital couples will visit the beach at moments to relax and share off stress from their busy schedules and thus was less concerned about the impacts of oil and gas.



CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

This chapter presents a summary of work done and the major results and findings made from the study. Also, are conclusions and recommendations stated in line with the purpose of the research.

6.1 Summary of work done

The idea of oil and gas production in Ghana is accepted with enthusiasm by all due to the benefits the nation stands to gain. However, concerns have been raised from the communities in the oil and gas enclave. Such concerns centre on loss of livelihood and ecosystem services among fisher folks, widespread sea weed incidence and death of marine mammals amongst others. For these reasons, test and control samples of water (sea water, borehole water and hand – dug well), soil and fish were collected from the Jomoro, Ellembele, Ahanta West and the Shama districts which is about 200 km away from oil and gas fields of which analysis proved consistency in fish catch yield. The samples were analysed using proxy indicators of ecosystem service quality to determine both direct and indirect impact that may result from the oil and gas exploration and production activities in the area. With the support of the Fisheries Commission's department in the Western Region, data was obtained for the assessment of fish catch trend in four (4) coastal districts in the area including the Shama district. A social survey conducted for 294 respondents elicited diverse views as perceptions on oil and gas activities on ecosystem services and human livelihood, beach and shoreline recreation and expectations upon visit to the beach and shoreline. The results from the study suggests that the pH of water samples could not be directly associated with oil and gas

activity which therefore be due to the composition of bedrock which has buffering ability. However, mean conductivity of water samples could be blamed on oil and gas activity from discharge of produced water, drilling muds etc. Also, could possibly be linked to some alternative livelihood activities undertaken by community members. Such activities are the sale of agro-chemicals, metal scraps and general inputs for building construction. Moreover, mean BOD values of water samples indicated pollution which based on the results might have affected parameters such as dissolved oxygen, salinity and turbidity levels. Heavy metals such as Nickel and chromium recorded higher concentrations in test samples relative to corresponding control samples. Generally, heavy metals are known to form part of produced water especially with Nickel which is used in gas pipelines and an ideal material for propeller shaft in boats.

Heavy metals prominent in fish samples were lead (Pb), Nickel (Ni) and Iron (Fe). The *Pomatomus saltatrix* (Blue fish) sampled from shama recorded lesser concentrations compared to the *Cynoscion regalis* (Weak fish) from the Half Assini sampling site. With respect to soil quality, the Bonferroni multiple test confirmed a strong negative correlation between pH, conductivity, cation exchange capacity and organic carbon while a positive correlation existed between conductivity, cation exchange capacity and organic carbon. Trend of fish catch in the enclave for the past 10 years was observed to be decreasing depending on a communities' closeness to the oil and gas fields. Livelihoods have also been impacted negatively. They no more obtain the fish catch left alone to enjoy and attract visitors to their serene and cosy beaches on their shoreline.

6.2 Conclusion

The study indicated a possible contamination of water from organic pollution. This was confirmed by the high EC and TDS in water (test and control) samples relative to WHO recommended limits. The pollution could be attributed to both direct and indirect anthropogenic sources of impacts such as the discharge of produced water resulting from the oil and gas activities. Others maybe from offshore sources such as oil discharge or spillage and alternative livelihood activities of the idle fisher folks onshore such as piggery production. This to a high extent confirms the resentments on poor catch levels and the death of marine organisms expressed by the residents. A high TDS and BOD have a direct relationship with DO to affect the growth, reproduction capacities, quality of fish and the survival of marine organisms.

The levels of heavy metals such as lead (Pb), Nickel (Ni) and Chromium (Cr) found in water samples brought to bear an ecosystem change in the enclave. These metals are associated with crude oil with other likely sources emerging from the sale of metal scraps by community members. Fish samples from communities closer to oil and gas fields may have been polluted with heavy metals. Weak fish (*Cynoscion regalis*) samples recorded higher concentrations of heavy metals compared to the Blue fish (*Pomatomous saltatrix*). Thus, fish and other marine organisms coupled with such a pollution possibility could be a source of the dwindling expectations for fish catch and death of marine organisms by residents. The study also established that the soil in the enclave was not fertile but could not be blamed on the oil and gas activities. Predominantly, sandy soil containing little organic matter was found in the enclave which might have resulted in decrease in the cation exchange capacity of the soil.

The study showed a decreasing trend in the amount of fish catch. Coastal communities very close to the oil and gas fields had a record of very poor catch compared to distant communities of about 200 km away from the fields.

It was confirmed from the perception of respondents that the fairly fertile status of soils could not be blamed on oil and gas activities. They expressed the fact that, the productivity of soil in the enclave was dependent on the type of crop a farmer decides to cultivate. The quality of fish was acceptable as it could not be associated with any disease or ailments. It could however be ascertained that the livelihoods of residents have been affected as their sole source of income of fishing was no more lucrative. It had also been difficult to find an alternative source of livelihood which had rendered living in communities in the area extremely unbearable. There had not been any benefit received with respect to the oil and gas production as immediate inhabitants of the surrounding communities. They could not boast of any community development agenda or projects offered to their communities.

It was further established that gender and educational background influenced public perception on the effects of oil and gas activities on beach and shoreline recreation. Thus, males and those with formal education associated mortality occurrences of marine organisms and littering of sea weeds on shoreline with oil and gas activities. However, marital status and duration of stay in a locality had no influence on such perception. In addition, the perception on expectations upon visit to the beaches and shoreline were highly influenced by gender, educational background and duration of stay but not marital status of respondents.

Based on the above facts and findings, the null hypothesis (H_0): “Oil and gas exploration and production have no significant impact on ecosystem services and human livelihood” is proved to be rejected, while the alternative hypothesis, H_1 : “Oil and gas exploration and production have significant impact on ecosystem services and human livelihood” fails to be rejected.

6.3 Recommendations

Based on the findings from the study, the following recommendations are suggested:

1. The Ministry for Fisheries and Aquaculture Development in conjunction with the Food and Drugs Authority must consistently check on the quality status of fish from our waters.
2. The EPA and other service research institutions such as the Water Research Institute (WRI), Soil Research Institute (SRI) must conduct a periodic monitoring to regularly ascertain water and soil quality in the enclave is within permissible limits.
3. The EPA must trace the source of the sea weeds and stop their spread. Besides, further studies must consider an investigation into Total Hydrocarbon Content of the sea weeds and fish species as increased concentrations can affect consumers along the food chain.
4. The Ministry for Fisheries and Aquaculture development should investigate the causes of low fish catch in the enclave. Such an investigation will aim to discover other contributing factors of low fish catch apart from oil and gas production to be able to offer lasting remedies.

5. The recently passed Petroleum Exploration & Production Law must be strictly enforced to the latter to ensure sustainability of the oil and gas industry on one hand and the development of the country as a whole. In this sense, oil and gas companies could be made to carry out post – impact assessment annually.

6. Alternative livelihood activities should be offered to the fisher folks in the enclave who are currently idle.

7. The Oil and Gas companies / partners must be compelled based on policies to adopt the communities /districts within which they operate and meet their needs.



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Appendix 1

**UNIVERSITY OF GHANA, LEGON
ENVIRONMENTAL SCIENCE PROGRAMME.**

A QUESTIONNAIRE ON SOCIO-CULTURAL VIEWS ON OIL AND GAS IMPACT
ON ECOSYSTEM SERVICES (PROVISIONING AND CULTURAL) IN COASTLINE
WEST OF CAPE THREE POINTS IN THE WESTERN REGION OF GHANA.

Dear Respondents,

The administrator of this questionnaire is a research student at the University of Ghana, Legon, seeking general information on the impacts of the oil and gas exploration and production on ecosystem services (fish stock, fish quality, water quality, soil quality and ecotourism and recreation) in coastline west of Cape Three Points. Therefore, whatever information you provide shall be treated with confidentiality and used only for academic purposes.

Please tick [☐] the correct option to the questions or spaces provided where necessary.

Thank you.

BACKGROUND INFORMATION

TOWN:

DATE:

(A).PERSONAL INFORMATION

NAME: SEX: M [☐] / F [☐] AGE:

1.0 MARITAL STATUS: (a) Married [] (b) Single [] (c) Separated [] (d) divorced []

2.0 EDUCATIONAL QUALIFICATION:

(a) None [] (b) Primary [] (c) MSLC/JHS [] (d) SHS [] (e) Poly/University []

3.0 OCCUPATION:

(a) Farmer [] (b) Fishermen [] (c) Trader [] (d) Civil/Public Servant (e) Student []

(f) Self-employed [] (g) Others []

4.0 HOW LONG HAVE YOU LIVED IN THIS LOCALITY?

(a) Below 5 yrs. [] (b) 5 – 10 yrs. [] (c) above 10 yrs. []

5.0 WHAT IS THE GENERAL OCCUPATION OF THE PEOPLE?

(a) Farming [] (b) Fishing [] (c) Trading [] (d) Public Servants [] (e) Others []

(B).OIL AND GAS ACTIVITIES AND QUALITY OF WATER AND SOIL

6.0 What is the main source of drinking water in your area?

(a) Pipe – borne [] (b) River/Stream [] (c) well [] (d) Rainwater [] (e) Others

7.0 Is the source wholesome for human consumption? YES/NO

8.0 If No, what is the nature of the water source?

(a) Poor taste [] (b) Bad smell [] (c) colour change [] (d) toxic [] (e) Others []

9.0 What has affected the nature/quality of the water?

(a) Oil residues [] (b) Soap residues [] (c) Mercury residues [] (d) Pesticides []

(e) Others []

10.0 What maybe the source of the contaminant into the water?

(a) Oil and Gas activities [] (b) Mining activities [] (c) Fishing activities [] (d) Farming [] (e) Others [].

11.0 What soil type do you have in your area? Is it productive? YES/NO

12.0 If No, what have you observed to be the cause?

.....

13.0 How do you rate the fertility status of soils of your area?

(a) Very fertile [] (b) Fairly fertile [] (c) Not fertile [] (d) Others []

(C). TRENDS IN FISH CATCH / STOCK AND QUALITY

14.0 How would you rate fish catch in your area 10 yrs ago?

(a) Very good [] (b) Good [] (c) Satisfactory [] (d) Poor

15.0 How would you rate fish catch in your area from 2014 to now?

(a) Very good [] (b) Good [] (c) Satisfactory [] (d) Poor []

16.0 What have you observed to be the factor behind the fish catch levels up until now?

(a) Fishing methods [] (b) Oil and Gas activities [] (c) Climate change [] (d) Foreign vessels [] (e) Others [].

17.0 Has there been experiences regarding mortality of fish and other marine organisms?YES/NO

18. If yes, what do you think is the cause of such experiences in your area?

(a) Oil and gas activities [] (b) Fishing methods [] (c) Foreign vessels [] (d) Climate change [] (e) Others []

19.Do you still enjoy the fish obtained from the sea and other water bodies by the fishermen?YES/NO

20. If No, what have you observed from the fish species made available by the fishermen?

(a) Poor taste [] (b) colour change [] (c) Bad smell [] (d) Toxic [] (e) Others

(D). OIL AND GAS IMPACT ON HUMAN WELL BEING/LIVELIHOOD AND ECOTOURISM /CULTURAL SERVICES.

21. What has been a major benefit derived from the oil and gas exploration and production in the area?

(a) Scholarships [] (b) Social amenities [] (c) Employment [] (d) Urbanization []

22. Is the sale of fish in your community or town still lucrative and to your expectation?

YES/NO. What is the reason for your answer?

.....

.....

23. Has there been any form of compensation payments for properties to deserving community members? YES/NO

If no, why has there not been payment of compensations?

24. Were the recipients satisfied with the levels of compensation issued? YES/NO

If no, why?

25. Has the beaches/shoreline been a place for relaxation, recreation and tourism? YES/NO

If no, why?

26. Do people still visit the beaches for relaxation, recreation, tourism and other activities? YES/NO

If no, why?

27. Are people's expectation met upon visiting the beaches or shoreline? YES/NO

If no, why?



Appendix 2**Table APX 1: ANOVA TABLE**

		Sum of Squares	df	Mean Square	F	P-value
pH	Between Groups	8.741	5	1.748	5.835	.003
	Within Groups	4.494	15	.300		
	Total	13.236	20			
Electrical Conductivity	Between Groups	83510782.964	5	16702156.593	12.682	.000
	Within Groups	19754462.274	15	1316964.152		
	Total	103265245.238	20			
Biochemical Oxygen Demand	Between Groups	30.316	5	6.063	10.252	.000
	Within Groups	8.871	15	.591		
	Total	39.187	20			
Dissolved Oxygen	Between Groups	67.562	5	13.512	2.237	.104
	Within Groups	90.623	15	6.042		
	Total	158.185	20			
Salinity	Between Groups	4504.469	5	900.894	11.745	.000
	Within Groups	1150.528	15	76.702		
	Total	5654.997	20			
Total Dissolved Solids	Between Groups	29490067.238	5	5898013.448	12.884	.000
	Within Groups	6866774.762	15	457784.984		
	Total	36356842.000	20			
Turbidity	Between Groups	647.749	5	129.550	3.590	.025
	Within Groups	541.244	15	36.083		
	Total	1188.993	20			
Lead	Between Groups	.000	5	.000	.	.
	Within Groups	.000	15	.000		
	Total	.000	20			
Cadmium	Between Groups	.000	5	.000	.	.
	Within Groups	.000	15	.000		
	Total	.000	20			
Nickel	Between Groups	1.015	5	.203	4.372	.012
	Within Groups	.696	15	.046		
	Total	1.711	20			
Chromium	Between Groups	.031	5	.006	.632	.679
	Within Groups	.147	15	.010		
	Total	.178	20			

Iron	Between Groups	18329.034	5	3665.807	1.026	.438
	Within Groups	53619.095	15	3574.606		
	Total	71948.130	20			

Table APX 2: A table showing analysis of variance on some soil quality parameters. ANOVA

Parameter		Sum of Squares	df	Mean Square	F	P-value
pH	Between Groups	1.557	2	.778	19.329	0.002*
	Within Groups	.242	6	.040		
	Total	1.798	8			
Conductivity	Between Groups	5967172.667	2	2983586.333	1343.017	0.000*
	Within Groups	13329.333	6	2221.556		
	Total	5980502.000	8			
Cation exchange capacity	Between Groups	48.741	2	24.371	1283.420	0.000*
	Within Groups	.114	6	.019		
	Total	48.855	8			
organic carbon	Between Groups	1.177	2	.589	913.362	0.000*
	Within Groups	.004	6	.001		
	Total	1.181	8			

Appendix 3

Multiple Comparisons

Bonferroni multiple test comparisons

Dependent Variable	(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	P-value	95% Confidence Interval	
						Lower Bound	Upper Bound
pH	Borehole	Sea water	-1.57464*	.34309	.004	-2.6893	-.4600
		Hand-dug well	-.72417	.41807	.533	-2.0825	.6341
		control borehole	-1.16750	.41807	.113	-2.5258	.1908
		Control sea water	-1.96250*	.47404	.009	-3.5027	-.4223
		Control hand-dug well	-1.55750*	.47404	.047	-3.0977	-.0173
	Sea water	Borehole	1.57464*	.34309	.004	.4600	2.6893
		Hand-dug well	.85048	.37773	.272	-.3767	2.0777
		control borehole	.40714	.37773	.883	-.8201	1.6344
		Control sea water	-.38786	.43888	.945	-1.8138	1.0380
		Control hand-dug well	.01714	.43888	1.000	-1.4088	1.4430
	Hand-dug well	Borehole	.72417	.41807	.533	-.6341	2.0825
		Sea water	-.85048	.37773	.272	-2.0777	.3767
		control borehole	-.44333	.44693	.914	-1.8954	1.0087
		Control sea water	-1.23833	.49969	.192	-2.8618	.3851
		Control hand-dug well	-.83333	.49969	.571	-2.4568	.7901
	control	Borehole	1.16750	.41807	.113	-.1908	2.5258

	borehole	Sea water	-.40714	.37773	.883	-1.6344	.8201
		Hand -dug well	.44333	.44693	.914	-1.0087	1.8954
		Control sea water	-.79500	.49969	.616	-2.4185	.8285
		Control hand- dug well	-.39000	.49969	.967	-2.0135	1.2335
	Control sea water	Borehole	1.96250*	.47404	.009	.4223	3.5027
		Sea water	.38786	.43888	.945	-1.0380	1.8138
		Hand -dug well	1.23833	.49969	.192	-.3851	2.8618
		control borehole	.79500	.49969	.616	-.8285	2.4185
	Control hand- dug well	Control hand- dug well	.40500	.54738	.973	-1.3734	2.1834
		Borehole	1.55750*	.47404	.047	.0173	3.0977
		Sea water	-.01714	.43888	1.000	-1.4430	1.4088
		Hand -dug well	.83333	.49969	.571	-.7901	2.4568
	Control hand- dug well	control borehole	.39000	.49969	.967	-1.2335	2.0135
		Control sea water	-.40500	.54738	.973	-2.1834	1.3734
	Electrical Conductivity	Borehole	-	719.29047	.000	-	-
		Sea water	4372.10714*	719.29047	.000	6709.0590	2035.1553
		Hand -dug well	-376.25000	876.48679	.998	-	2471.4277
		control borehole	113.41667	876.48679	1.000	-	2961.0943
		Control sea water	-2653.25000	993.84260	.140	-	575.7130
		Control hand- dug well	-103.25000	993.84260	1.000	-	3125.7130
	Sea	Borehole	4372.10714*	719.29047	.000	2035.1553	6709.0590

water	Hand -dug well	3995.85714*	791.91274	.002	1422.9579	6568.7564
	control borehole	4485.52381*	791.91274	.001	1912.6245	7058.4231
	Control sea water	1718.85714	920.11946	.456	- 1270.5817	4708.2960
	Control hand- dug well	4268.85714*	920.11946	.004	1279.4183	7258.2960
Hand dug well	- Borehole	376.25000	876.48679	.998	- 2471.4277	3223.9277
	Sea water	- 3995.85714*	791.91274	.002	- 6568.7564	- 1422.9579
	control borehole	489.66667	937.00379	.994	- 2554.6288	3533.9621
	Control sea water	-2277.00000	1047.60208	.305	- 5680.6258	1126.6258
	Control hand- dug well	273.00000	1047.60208	1.000	- 3130.6258	3676.6258
control borehole	Borehole	-113.41667	876.48679	1.000	- 2961.0943	2734.2610
	Sea water	- 4485.52381*	791.91274	.001	- 7058.4231	- 1912.6245
	Hand -dug well	-489.66667	937.00379	.994	- 3533.9621	2554.6288
	Control sea water	-2766.66667	1047.60208	.147	- 6170.2925	636.9591
	Control hand- dug well	-216.66667	1047.60208	1.000	- 3620.2925	3186.9591
Control sea water	Borehole	2653.25000	993.84260	.140	-575.7130	5882.2130
	Sea water	-1718.85714	920.11946	.456	- 4708.2960	1270.5817
	Hand -dug well	2277.00000	1047.60208	.305	- 1126.6258	5680.6258
	control borehole	2766.66667	1047.60208	.147	-636.9591	6170.2925

	Control hand-dug well	2550.00000	1147.59059	.284	- 1178.4853	6278.4853
	Control hand-dug well Borehole	103.25000	993.84260	1.000	- 3125.7130	3332.2130
	Sea water	- 4268.85714*	920.11946	.004	- 7258.2960	- 1279.4183
	Hand -dug well	-273.00000	1047.60208	1.000	- 3676.6258	3130.6258
	control borehole	216.66667	1047.60208	1.000	- 3186.9591	3620.2925
	Control sea water	-2550.00000	1147.59059	.284	- 6278.4853	1178.4853
Biochemical Oxygen Demand	Borehole Sea water	1.76536*	.48201	.023	.1993	3.3314
	Hand -dug well	1.93917*	.58735	.045	.0309	3.8475
	control borehole	1.52583	.58735	.158	-.3825	3.4341
	Control sea water	4.27750*	.66600	.000	2.1137	6.4413
	Control hand-dug well	3.34750*	.66600	.002	1.1837	5.5113
	Sea water Borehole	-1.76536*	.48201	.023	-3.3314	-.1993
	Hand -dug well	.17381	.53068	.999	-1.5504	1.8980
	control borehole	-.23952	.53068	.997	-1.9637	1.4846
	Control sea water	2.51214*	.61659	.010	.5088	4.5154
	Control hand-dug well	1.58214	.61659	.166	-.4212	3.5854
	Hand - Borehole	-1.93917*	.58735	.045	-3.8475	-.0309
	Sea water	-.17381	.53068	.999	-1.8980	1.5504
	control borehole	-.41333	.62791	.984	-2.4534	1.6267
	Control sea water	2.33833*	.70202	.043	.0575	4.6192

	Control hand- dug well	1.40833	.70202	.383	-.8725	3.6892
control borehole	Borehole	-1.52583	.58735	.158	-3.4341	.3825
	Sea water	.23952	.53068	.997	-1.4846	1.9637
	Hand -dug well	.41333	.62791	.984	-1.6267	2.4534
	Control sea water	2.75167*	.70202	.014	.4708	5.0325
	Control hand- dug well	1.82167	.70202	.159	-.4592	4.1025
Control sea water	Borehole	-4.27750*	.66600	.000	-6.4413	-2.1137
	Sea water	-2.51214*	.61659	.010	-4.5154	-.5088
	Hand -dug well	-2.33833*	.70202	.043	-4.6192	-.0575
	control borehole	-2.75167*	.70202	.014	-5.0325	-.4708
	Control hand- dug well	-.93000	.76903	.826	-3.4285	1.5685
Control hand- dug well	Borehole	-3.34750*	.66600	.002	-5.5113	-1.1837
	Sea water	-1.58214	.61659	.166	-3.5854	.4212
	Hand -dug well	-1.40833	.70202	.383	-3.6892	.8725
	control borehole	-1.82167	.70202	.159	-4.1025	.4592
	Control sea water	.93000	.76903	.826	-1.5685	3.4285
Dissolve d Oxygen	Borehole	1.95543	1.54061	.796	-3.0499	6.9608
	Hand -dug well	2.07733	1.87729	.871	-4.0219	8.1766
	control borehole	-3.04933	1.87729	.596	-9.1486	3.0499
	Control sea water	.34400	2.12865	1.000	-6.5719	7.2599
	Control hand- dug well	-1.31100	2.12865	.988	-8.2269	5.6049

Sea water	Borehole	-1.95543	1.54061	.796	-6.9608	3.0499
	Hand -dug well	.12190	1.69615	1.000	-5.3888	5.6326
	control borehole	-5.00476	1.69615	.086	-10.5155	.5060
	Control sea water	-1.61143	1.97075	.960	-8.0143	4.7915
	Control hand- dug well	-3.26643	1.97075	.577	-9.6693	3.1365
Hand - dug well	Borehole	-2.07733	1.87729	.871	-8.1766	4.0219
	Sea water	-.12190	1.69615	1.000	-5.6326	5.3888
	control borehole	-5.12667	2.00691	.169	-11.6471	1.3937
	Control sea water	-1.73333	2.24380	.968	-9.0234	5.5567
	Control hand- dug well	-3.38833	2.24380	.664	-10.6784	3.9017
control borehole	Borehole	3.04933	1.87729	.596	-3.0499	9.1486
	Sea water	5.00476	1.69615	.086	-.5060	10.5155
	Hand -dug well	5.12667	2.00691	.169	-1.3937	11.6471
	Control sea water	3.39333	2.24380	.662	-3.8967	10.6834
	Control hand- dug well	1.73833	2.24380	.968	-5.5517	9.0284
Control sea water	Borehole	-.34400	2.12865	1.000	-7.2599	6.5719
	Sea water	1.61143	1.97075	.960	-4.7915	8.0143
	Hand -dug well	1.73333	2.24380	.968	-5.5567	9.0234
	control borehole	-3.39333	2.24380	.662	-10.6834	3.8967
	Control hand- dug well	-1.65500	2.45796	.982	-9.6408	6.3308
Control hand-	Borehole	1.31100	2.12865	.988	-5.6049	8.2269
	Sea water	3.26643	1.97075	.577	-3.1365	9.6693

	dug well	Hand well	-dug well	3.38833	2.24380	.664	-3.9017	10.6784
		control borehole		-1.73833	2.24380	.968	-9.0284	5.5517
		Control sea water		1.65500	2.45796	.982	-6.3308	9.6408
Salinity	Borehole	Sea water		-29.82500*	5.48934	.001	-47.6597	-11.9903
		Hand well	-dug well	-.22500	6.68900	1.000	-21.9574	21.5074
		control borehole		.06500	6.68900	1.000	-21.6674	21.7974
		Control sea water		-29.12500*	7.58462	.016	-53.7672	-4.4828
		Control hand-dug well		-.22500	7.58462	1.000	-24.8672	24.4172
	Sea water	Borehole		29.82500*	5.48934	.001	11.9903	47.6597
		Hand well	-dug well	29.60000*	6.04357	.002	9.9646	49.2354
		control borehole		29.89000*	6.04357	.002	10.2546	49.5254
		Control sea water		.70000	7.02199	1.000	-22.1142	23.5142
		Control hand-dug well		29.60000*	7.02199	.008	6.7858	52.4142
	Hand dug well	Borehole		.22500	6.68900	1.000	-21.5074	21.9574
		Sea water		-29.60000*	6.04357	.002	-49.2354	-9.9646
		control borehole		.29000	7.15084	1.000	-22.9429	23.5229
		Control sea water		-28.90000*	7.99489	.025	-54.8751	-2.9249
		Control hand-dug well		.00000	7.99489	1.000	-25.9751	25.9751
	control borehole	Borehole		-.06500	6.68900	1.000	-21.7974	21.6674
		Sea water		-29.89000*	6.04357	.002	-49.5254	-10.2546
		Hand well	-dug well	-.29000	7.15084	1.000	-23.5229	22.9429

	Control sea water	-29.19000*	7.99489	.024	-55.1651	-3.2149
	Control hand-dug well	-.29000	7.99489	1.000	-26.2651	25.6851
	Control Borehole	29.12500*	7.58462	.016	4.4828	53.7672
sea water	Sea water	-.70000	7.02199	1.000	-23.5142	22.1142
	Hand -dug well	28.90000*	7.99489	.025	2.9249	54.8751
	control borehole	29.19000*	7.99489	.024	3.2149	55.1651
	Control hand-dug well	28.90000*	8.75796	.046	.4457	57.3543
Control hand-dug well	Borehole	.22500	7.58462	1.000	-24.4172	24.8672
	Sea water	-29.60000*	7.02199	.008	-52.4142	-6.7858
	Hand -dug well	.00000	7.99489	1.000	-25.9751	25.9751
	control borehole	.29000	7.99489	1.000	-25.6851	26.2651
	Control sea water	-28.90000*	8.75796	.046	-57.3543	-.4457
Total Dissolved Solids	Borehole Sea water	-	424.08030	.000	-	-
	Hand -dug well	2605.71429*	516.76033	.997	3983.5377	1227.8909
	control borehole	-238.66667	516.76033	1.000	-	-
	Control sea water	93.33333	585.95114	.301	1917.6045	1440.2712
	Control hand-dug well	-1279.00000	585.95114	1.000	1585.6045	1772.2712
	Sea water	-9.00000	585.95114	1.000	-	-
	Borehole	2605.71429*	424.08030	.000	3182.7366	624.7366
	Hand -dug well	2367.04762*	466.89704	.002	-	-
	control borehole	2699.04762*	466.89704	.000	1912.7366	1894.7366
	Borehole	2605.71429*	424.08030	.000	1227.8909	3983.5377
	Hand -dug well	2367.04762*	466.89704	.002	850.1140	3883.9812
	control borehole	2699.04762*	466.89704	.000	1182.1140	4215.9812

	Control sea water	1326.71429	542.48534	.202	-435.8033	3089.2319
	Control hand-dug well	2596.71429*	542.48534	.003	834.1967	4359.2319
Hand - dug well	Borehole	238.66667	516.76033	.997	-1440.2712	1917.6045
	Sea water	-2367.04762*	466.89704	.002	-3883.9812	-850.1140
	control borehole	332.00000	552.44003	.989	-1462.8601	2126.8601
	Control sea water	-1040.33333	617.64673	.561	-3047.0479	966.3812
	Control hand-dug well	229.66667	617.64673	.999	-1777.0479	2236.3812
control borehole	Borehole	-93.33333	516.76033	1.000	-1772.2712	1585.6045
	Sea water	-2699.04762*	466.89704	.000	-4215.9812	-1182.1140
	Hand -dug well	-332.00000	552.44003	.989	-2126.8601	1462.8601
	Control sea water	-1372.33333	617.64673	.284	-3379.0479	634.3812
	Control hand-dug well	-102.33333	617.64673	1.000	-2109.0479	1904.3812
Control sea water	Borehole	1279.00000	585.95114	.301	-624.7366	3182.7366
	Sea water	-1326.71429	542.48534	.202	-3089.2319	435.8033
	Hand -dug well	1040.33333	617.64673	.561	-966.3812	3047.0479
	control borehole	1372.33333	617.64673	.284	-634.3812	3379.0479
	Control hand-dug well	1270.00000	676.59810	.451	-928.2457	3468.2457
Control hand-	Borehole	9.00000	585.95114	1.000	-1894.7366	1912.7366

	dug well	Sea water	- 2596.71429*	542.48534	.003	- 4359.2319	-834.1967
		Hand -dug well	-229.66667	617.64673	.999	- 2236.3812	1777.0479
		control borehole	102.33333	617.64673	1.000	- 1904.3812	2109.0479
		Control sea water	-1270.00000	676.59810	.451	- 3468.2457	928.2457
Turbidity	Borehole	Sea water	-11.45786	3.76503	.073	-23.6903	.7746
		Hand -dug well	-.22167	4.58785	1.000	-15.1275	14.6841
		control borehole	.44833	4.58785	1.000	-14.4575	15.3541
		Control sea water	-9.57500	5.20214	.471	-26.4766	7.3266
		Control hand- dug well	.42500	5.20214	1.000	-16.4766	17.3266
	Sea water	Borehole	11.45786	3.76503	.073	-.7746	23.6903
		Hand -dug well	11.23619	4.14516	.131	-2.2313	24.7037
		control borehole	11.90619	4.14516	.099	-1.5613	25.3737
		Control sea water	1.88286	4.81624	.999	-13.7650	17.5307
		Control hand- dug well	11.88286	4.81624	.195	-3.7650	27.5307
	Hand - dug well	Borehole	.22167	4.58785	1.000	-14.6841	15.1275
		Sea water	-11.23619	4.14516	.131	-24.7037	2.2313
		control borehole	.67000	4.90462	1.000	-15.2650	16.6050
		Control sea water	-9.35333	5.48353	.548	-27.1692	8.4625
		Control hand- dug well	.64667	5.48353	1.000	-17.1692	18.4625
	control borehole	Borehole	-.44833	4.58785	1.000	-15.3541	14.4575
		Sea water	-11.90619	4.14516	.099	-25.3737	1.5613

		Hand -dug well	-0.67000	4.90462	1.000	-16.6050	15.2650
		Control sea water	-10.02333	5.48353	.478	-27.8392	7.7925
		Control hand- dug well	-.02333	5.48353	1.000	-17.8392	17.7925
	Control sea water	Borehole	9.57500	5.20214	.471	-7.3266	26.4766
		Sea water	-1.88286	4.81624	.999	-17.5307	13.7650
		Hand -dug well	9.35333	5.48353	.548	-8.4625	27.1692
		ontrol borehole	10.02333	5.48353	.478	-7.7925	27.8392
		Control hand- dug well	10.00000	6.00691	.572	-9.5163	29.5163
	Control hand- dug well	Borehole	-.42500	5.20214	1.000	-17.3266	16.4766
		Sea water	-11.88286	4.81624	.195	-27.5307	3.7650
		Hand -dug well	-.64667	5.48353	1.000	-18.4625	17.1692
		ontrol borehole	.02333	5.48353	1.000	-17.7925	17.8392
		Control sea water	-10.00000	6.00691	.572	-29.5163	9.5163
Nickel	Borehole	Sea water	-.253000	.135052	.453	-.69178	.18578
	e	Hand -dug well	.080000	.164567	.996	-.45467	.61467
		ontrol borehole	.315000	.164567	.431	-.21967	.84967
		Control sea water	.220500	.186601	.839	-.38576	.82676
		Control hand- dug well	.284000	.186601	.657	-.32226	.89026
	Sea water	Borehole	.253000	.135052	.453	-.18578	.69178
		Hand -dug well	.333000	.148687	.277	-.15008	.81608
		ontrol borehole	.568000*	.148687	.017	.08492	1.05108

	Control sea water	.473500	.172759	.124	-.08779	1.03479
	Control hand-dug well	.537000	.172759	.065	-.02429	1.09829
Hand - dug well	Borehole	-.080000	.164567	.996	-.61467	.45467
	Sea water	-.333000	.148687	.277	-.81608	.15008
	control borehole	.235000	.175929	.762	-.33659	.80659
	Control sea water	.140500	.196695	.977	-.49856	.77956
	Control hand-dug well	.204000	.196695	.898	-.43506	.84306
control borehole	Borehole	-.315000	.164567	.431	-.84967	.21967
	Sea water	-.568000*	.148687	.017	-1.05108	-.08492
	Hand -dug well	-.235000	.175929	.762	-.80659	.33659
	Control sea water	-.094500	.196695	.996	-.73356	.54456
	Control hand-dug well	-.031000	.196695	1.000	-.67006	.60806
Control sea water	Borehole	-.220500	.186601	.839	-.82676	.38576
	Sea water	-.473500	.172759	.124	-1.03479	.08779
	Hand -dug well	-.140500	.196695	.977	-.77956	.49856
	ontrol borehole	.094500	.196695	.996	-.54456	.73356
	Control hand-dug well	.063500	.215469	1.000	-.63655	.76355
Control hand-dug well	Borehole	-.284000	.186601	.657	-.89026	.32226
	Sea water	-.537000	.172759	.065	-1.09829	.02429
	Hand -dug well	-.204000	.196695	.898	-.84306	.43506
	ontrol borehole	.031000	.196695	1.000	-.60806	.67006

		Control sea water	-.063500	.215469	1.000	-.76355	.63655
Chromium	Borehole	Sea water	.049786	.062101	.963	-.15198	.25155
		Hand-dug well	.024833	.075673	.999	-.22103	.27069
		control borehole	.069167	.075673	.937	-.17669	.31503
		Control sea water	.120000	.085805	.727	-.15878	.39878
		Control hand-dug well	.114500	.085805	.763	-.16428	.39328
	Sea water	Borehole	-.049786	.062101	.963	-.25155	.15198
		Hand-dug well	-.024952	.068371	.999	-.24709	.19718
		control borehole	.019381	.068371	1.000	-.20275	.24152
		Control sea water	.070214	.079440	.945	-.18788	.32831
		Control hand-dug well	.064714	.079440	.960	-.19338	.32281
	Hand-dug well	Borehole	-.024833	.075673	.999	-.27069	.22103
		Sea water	.024952	.068371	.999	-.19718	.24709
		control borehole	.044333	.080898	.993	-.21850	.30717
		Control sea water	.095167	.090447	.892	-.19869	.38902
		Control hand-dug well	.089667	.090447	.914	-.20419	.38352
	control borehole	Borehole	-.069167	.075673	.937	-.31503	.17669
		Sea water	-.019381	.068371	1.000	-.24152	.20275
		Hand-dug well	-.044333	.080898	.993	-.30717	.21850
		Control sea water	.050833	.090447	.992	-.24302	.34469

		Control hand- dug well	.045333	.090447	.995	-.24852	.33919
	Control sea water	Borehole	-.120000	.085805	.727	-.39878	.15878
		Sea water	-.070214	.079440	.945	-.32831	.18788
		Hand -dug well	-.095167	.090447	.892	-.38902	.19869
		ontrol borehole	-.050833	.090447	.992	-.34469	.24302
		Control hand- dug well	-.005500	.099079	1.000	-.32741	.31641
	Control hand- dug well	Borehole	-.114500	.085805	.763	-.39328	.16428
		Sea water	-.064714	.079440	.960	-.32281	.19338
		Hand -dug well	-.089667	.090447	.914	-.38352	.20419
		ontrol borehole	-.045333	.090447	.995	-.33919	.24852
		Control sea water	.005500	.099079	1.000	-.31641	.32741
Iron	Borehole	Sea water	-64.148500	37.474120	.545	-185.90072	57.60372
		Hand -dug well	-.381833	45.663848	1.000	-148.74222	147.97856
		ontrol borehole	.149833	45.663848	1.000	-148.21056	148.51022
		Control sea water	-33.277500	51.777937	.986	-201.50237	134.94737
		Control hand- dug well	.017000	51.777937	1.000	-168.20787	168.24187
	Sea water	Borehole	64.148500	37.474120	.545	-57.60372	185.90072
		Hand -dug well	63.766667	41.257648	.643	-70.27812	197.81145
		ontrol borehole	64.298333	41.257648	.635	-69.74645	198.34312
		Control sea water	30.871000	47.937055	.985	-124.87496	186.61696

	Control hand-dug well	64.165500	47.937055	.760	-91.58046	219.91146
Hand - dug well	Borehole	.381833	45.663848	1.000	-147.97856	148.74222
	Sea water	-63.766667	41.257648	.643	-197.81145	70.27812
	Control borehole	.531667	48.816707	1.000	-158.07226	159.13559
	Control sea water	-32.895667	54.578738	.989	-210.22025	144.42891
	Control hand-dug well	.398833	54.578738	1.000	-176.92575	177.72341
Control borehole	Borehole	-.149833	45.663848	1.000	-148.51022	148.21056
	Sea water	-64.298333	41.257648	.635	-198.34312	69.74645
	Hand -dug well	-.531667	48.816707	1.000	-159.13559	158.07226
	Control sea water	-33.427333	54.578738	.988	-210.75191	143.89725
	Control hand-dug well	-.132833	54.578738	1.000	-177.45741	177.19175
Control sea water	Borehole	33.277500	51.777937	.986	-134.94737	201.50237
	Sea water	-30.871000	47.937055	.985	-186.61696	124.87496
	Hand -dug well	32.895667	54.578738	.989	-144.42891	210.22025
	Control borehole	33.427333	54.578738	.988	-143.89725	210.75191
	Control hand-dug well	33.294500	59.788012	.992	-160.95485	227.54385
Control hand-	Borehole	-.017000	51.777937	1.000	-168.24187	168.20787

dug well	Sea water	-64.165500	47.937055	.760	-	219.91146	91.58046
	Hand -dug well	-.398833	54.578738	1.000	-	177.72341	176.92575
	ontrol borehole	.132833	54.578738	1.000	-	177.19175	177.45741
	Control sea water	-33.294500	59.788012	.992	-	227.54385	160.95485

*, The mean difference is significant at the 0.05 level.

