GIS-AHP Based Quarry Site Suitability Analysis and Characterization of Crushed Stone Aggregates for Construction use in Jigjiga Town, Eastern Ethiopia

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Declaration

I hereby declare that this Master Thesis entitled "**GIS-AHP Based Quarry Site Suitability Analysis and Characterization of Crushed Stone Aggregates for Construction use in Jigjiga Town, Eastern Ethiopia**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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I the advisor of the thesis entitled "**GIS-AHP Based Quarry Site Suitability Analysis and Characterization of Crushed Stone Aggregates for Construction use in Jigjiga Town, Eastern Ethiopia**" and developed by **Hassan Abdikadir**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by **Hassan Abdikadir** have read and evaluated the thesis entitled "**GIS-AHP Based Quarry Site Suitability Analysis and Characterization of Crushed Stone Aggregates for Construction use in Jigjiga Town, Eastern Ethiopia**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in **Engineering Geology**.

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Abstract

Crushed stone aggregates are the main constituent of concrete. The recent development of Portland cement has increased the use of geological material for concrete production. The crushed stone aggregates are produced by quarrying activity. Nevertheless the activity causes major socio-economic and environmental impacts. Therefore appropriate measures should be taken during quarry site selection and operation. The main objective of this study is to select suitable quarry sites and to assess the suitability of crushed stone aggregates for construction in Jigjiga town. The suitable quarry sites were identified by adopting a GIS- AHP approach in which 8 factors were considered for quarry site selection. In the process of suitable quarry site selection, weighted overlay analyses was used in which land use land cover, distance to buildup area, overburden thickness, distance to water bodies, distance to road, relative relief and slope angle of the area were considered to produce the preliminary quarry suitability map. Finally the final quarry site suitability map of the study was generated, using math algebra product of lithology and preliminary quarry site suitability map. The final preliminary quarry site suitability map showed that 28.2% (598.4 Km^2) of the study area is highly suitable for quarry sites where as 25.6 %(543.2 Km^2), of the area is unsuitable. In contrast the suitability of 11.6 % (246.7Km^2) and 34.6% (735.6Km^2) is moderate and low respectively. Following the suitable quarry site selection rock aggregates were collected from highly suitable areas for quarry site and physico-mechanical properties such as water absorption, specific gravity, aggregate shape test, crushing value (ACV) Los Angeles abrasion value (LAV), Impact value (AIV), sodium sulphate soundness test and petrographic analyses were conducted to assess the suitability of the aggregates for construction use. Aggregates from quarries 1, 2, 3, 9 and 10 have shown good quality in term of physical, mechanical properties and also stable in term of alkali-silica reactivity

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List of Abbreviations and Acronyms

DEM	Digital Elevation Model
GSE	Geological survey of Ethiopia
GPS	Global Positioning System
NASA	National Aeronautics and Space Administration
Ph.D.	Doctor of Philosophy
UCS	Uniaxial Compression Strength
BS	British Standard
ASTM	American Society for Testing and Materials
AASHTO	American Association of State Highways and Transportation Officials
GIS	Geographic Information System

Chapter one

1. Introduction

1.1 Background

The demand of geological construction material is rising globally due to the growth and development of infrastructures including highways, airports, dams, hospitals, and other public and private buildings. The maintenance and development of these infrastructures requires large amount of geological construction material which is produced by quarrying process. Quarry is a type of open-pit mine from which rocks or minerals are extracted (El-Dine et al., 2009), the end product materials from quarries include crushed stone which is very important in modern civil engineering and construction works. Nevertheless, this activity involves crushing; blasting and excavating raw geological material from the ground which causes water pollution, land degradation, noise pollution, vibrations and landslides (Sreenivasa and Ravanu, 2014). Therefore the environmental impact of the quarry operation, the economic viability and the aggregate quantity and quality has to be considered during quarry site selection. However, in most of African nations, environmental sustainability is not taken into account while choosing, managing, and operating quarries (Darwish et al., 2011). This frequently results in land collapse, land conversion, environmental contamination as well as possible effects on the local population (Pal and Mandal, 2017). Therefore, proper site selection, quarry planning, and management are crucial not only the operation of a profitable quarry but also for quality control and long-term environmental management (Egesi and Nwosu, 2018).

The production of aggregates resources initially requires selecting suitable potential quarry site (Regessa et al., 2015).The selection of suitable quarry site is controlled by, rock type (the quality of rocks), topographic condition (slope angle and relative relief) of the site, land use/ land cover of the site, distance of the quarry site from the market, distance to build up area, distance from water bodies, overburden soil thickness of the site and depth to groundwater (Regessa et al., 2015; Gudissa et al., 2020). In recent years, Multi-criteria decision making methods and Geographic Information System (GIS) are widely used as a tool for site suitability selection (Uyan, 2013). The selection of suitable quarry sites involves consideration of multiple factors which makes the task very challenging, hence the integration of mathematical techniques such as analytical hierarchy process (AHP) and GIS are widely applied to select suitable sites, the techniques has been previously employed for Quarry site selection (Guddisa et al, .2020), groundwater recharge site selection (Rajasekhar et al., 2019), and landfill site (Ebistu and Minale, 2013; Dimopoulou et al., 2013; Akanwa et al.,2017).

Furthermore beside the environmental and socio-economic aspect of the site also the quality of aggregates that the quarry possesses has to be greatly evaluated. Crushed stones are essential input for construction industry and manufacturing of concrete products, road materials, railway ballast, and other ancillary products (Adinkrah-Appiah et al., 2016). In concrete and pavement works, they occupy nearly 75% and 80–90% of the total volume of the mix respectively (Jose Renato et al., 2015). Therefore crushed stone is the dominant constituents of concrete and pavement and hence it influences the strength and durability of concrete and pavement to a great extent. Therefore characterizing the quality of crushed stone aggregate is important to assure the safety and long lasting performance of the engineering structures by selecting quality material that meet the standard specifications related to strength and durability. The aggregates used as road stones must possess high resistance to crushing and heavy traffic wheel load; has to be tough enough to resist high impacts caused by the jumping of the steel wheels and severe abrasion resistance, it also has to be sound enough to resist weathering (Bell, 2007). Hence, the material quality has to be studied to assure the safety and long lasting performance of the structures.

Following these, this study aims to locate suitable quarry sites and produce preliminary quarry site suitability map and to characterize the engineering property of crushed stone aggregates for Jigjiga town. Jigjiga is the biggest and highly developing town in Somali regional state, the construction of infrastructures need plenty of construction material supply, hence locating suitable quarry sites for the town is important to assess the construction material needed for infrastructure developments.

1.2 Statement of the problem

The demand of crushed stone aggregates for construction purpose in Jigjiga town is increasing due to expansion and development of infrastructures such as highways, hospitals and other public and private buildings. It is therefore, essential to locate suitable quarry sites to answer the demand of construction material of the city. Locating suitable quarry sites for the town eases the accessibility and production of raw construction material and reduces environmental impact associated with quarry operations. Despite this, currently crushed stone aggregates are produced without prior evaluation of the suitability of the quarry site, which results in environmental and socio-economic impact in the study area.

Crushed stone aggregates are used as aggregates for Portland cement concrete mix and asphaltic concrete. Generally the mechanical and chemical property of the aggregates affects the strength and durability of the concrete, therefore studying the quality of the aggregates assures the safety and durability of the infrastructures. Crushed stone aggregates are highly used for construction purpose in Jigjiga town regardless of the quality considerations which results failure of many infrastructures before the designed engineering life span. Hence considering the increasing demand of crushed stone aggregates for construction use in the town, this study aims to locate optimal quarry sites and characterize the material quality from selected suitable quarry sites for construction use in Jigjiga town.

1.3 Objective of the study

1.3.1 General objective

The main objective of this study is to make a comprehensive appraisal of rocks with regard to its suitability as crushed stone, aggregate and to select optimal quarry sites for Jigjiga town.

1.3.2 Specific objectives

The specific objectives of this study are:

- To producing quarry site suitability map of the study area at scale of 1: 50,000
- To determine physico-mechanical properties of crushed stone aggregate from selected suitable quarry sites
- To determine the mineral composition of aggregates by conducting a petrographic thin section analysis.

- To determine the suitability of crushed stone aggregates for construction use following current standard specifications

1.4 Significance of the study

The rapid development of infrastructures in Jigjiga town has increased the demand of crushed stone aggregates for construction uses. Crushed stone aggregates are produced through quarrying operation. Nevertheless inappropriate quarry operation causes environmental and socio-economic impact. Therefore selection of suitable quarry site reduces the environmental and socio-economic impact of poor quarrying operation as a result this study aims to delineate the suitable quarry sites available in the study area in order to avoid environmental and socio-economic impact of poor quarry operation. On other hand, the quality of aggregates contribute to the safety and the long lasting performance of engineering structures, therefore, this study also characterizes the engineering property of crushed stone aggregates to assess the suitability of the available material for construction use in the town, which in turn assures the safety and durability of engineering structures.

Chapter two

2. Literature review

2.1 Introduction

A quarry is a type of open-pit mine from which rock or minerals are extracted (El-Dine et al., 2009), Coppin and Bradshaw (1982) also stated that quarrying is an open cast excavation from which fairly massive and deep deposits of hard or soft rocks are extracted. Quarrying involves crushing, blasting, and excavating raw geological construction material from the ground. Hence this activity can cause pollution, noise, and environmental impact in the vicinity of the quarry site. Therefore, appropriate measures should be taken to locate the suitable quarry site that possesses less environmental impact with good quality construction material. Consequently suitable quarry site selection is a process of finding a suitable place that possesses less socio-economic and environmental impact with good quality construction material. However, in most African nations, environmental sustainability is not taken into account while choosing, managing, and operating quarries (Darwish et al., 2011). Furthermore, suitable site selection, quarry planning, and management are important not only for the operation of a profitable quarry but also for quality control and long-term environmental management (Egesi and Nwosu, 2018). Therefore, all governing factors for selecting a suitable quarry site must be taken into account in order to ensure the socio-economic and environmental sustainability.

According to Regessa et al. (2015), and Guddisa et al. (2020), the selection of suitable quarry site is controlled by, rock type (the quality of rocks), topographic condition (slope angle and relative relief) of the site, land use/ land cover of the site, distance of the quarry site from the market, distance to build up area, distance from water bodies, overburden soil thickness of the site and depth to groundwater.

2.2 Suitable site selection using a GIS-AHP based Approach

Suitable site selection involves decision making by considering many alternatives using mathematical techniques. Various multi-criteria decision making (MCDM) techniques have been developed and previously applied for regional planning, agricultural land and water management purposes (Tiwari et al., 1999). In recent years multi-criteria decision making methods and Geographic Information System (GIS) are widely used as a tool for suitable site selection (Uyan, 2013). The combination of GIS and multi-criteria evaluation (MCE) techniques has been employed more frequently as a spatial decision support system (SDSS) for determining suitable locations (Uyan, 2013). MCE methods are a frequently utilized concept that provides individuals with a strategy to enable them choose the best alternative among a variety of criteria (Eastman JR et al., 1995; Wu, 1998; Murphy, 2003; Brink and marx, 2013).

Analytical Hierarchy process (AHP) is one of multi-criteria decision making tools, which is used for determining appropriate decision (Satty, 1980). The method has been previously used for various site suitability selections such as; land fill site (Yoxas et al., 2011; Zelenović et al., 2012; Ebistu and Minale, 2013; Dimopoulou et al., 2013; Khan and Smadder, 2015; Chabuk et al., 2016; Chabuk et al., 2017; Alkaradaghi et al., 2019), groundwater recharge site (Rajasekhar et al., 2019) , mining methods (Ataei et al., 2008; Manadal and Mondal, 2016). The combination of AHP and GIS has been employed for suitable quarry site selection (Gudissa et al., 2020). The major characteristic of the AHP method is the use of pair-wise comparisons, which are used both to compare the alternatives with respect to the various criteria and to estimate criteria weights (Løken, 2007). The weight of each factor, determined with aid of pairwise comparison matrix is used in GIS environment to produce suitability map using weighted overlay analysis.

2.3 Impact of quarry site

Quarrying is the process of extracting useful industrial minerals from the earth crust (Akanwa et al., 2017).It is an activity where stones are excavated for purpose of being used for constructions of roads, dams and buildings. They are mostly gravel, sand and crushed aggregates. These materials are indeed inevitable in every community buildings and infrastructures in which without their existence and usage there will be no built engineering structure (Akanwa et al., 2017). However quarry operation causes a wide variety of environmental and social impacts in the vicinity of the quarry site. According to Sreenivasa and Ravanu (2014), the major impacts of quarries to the environment are water pollution, land degradation, noise pollution, vibrations and landslides. Quarrying operations can adversely alter pre-existing ecosystems, and change hydrogeological and hydrological regimes (Ozcan et al., 2012). Runoff from quarry sites flows very rapidly towards nearby water bodies which makes the lakes and streams susceptible to pollution from quarries (Pal and Mandal, 2017). According to Guddisa et al. (2020), the community residing near the quarry sites experiences annoyance; nuisance, and sleep disturbance due to vibration, noise, fly rock, and dust caused by blasting during quarry operation.

Quarry operation can cause health problem depending on the chemical composition of the quarry material. Blasting for extraction of rocks may cause noise pollution and the dust during quarrying operation contributes the chemical elements which cause air pollution (Zawawi and Ibrahim, 2021).These chemicals have great potential to harm human health and can destroy habitats and a variety of species (Mabogunje, 2008 as cited in Lameed and Ayodele,2010) . According to Asante et al. (2014),Carney (1998) and Langer (2001), 4 million people have been reported to die every year from acute respiratory problems in developing countries, the most part being aggravated by environmental pollution emanating from quarrying, sandblasting and emission of dangerous chemicals.

The exploitation of solid materials by quarrying involves land clearing which cause huge loss of vegetation cover due to the fact that its operations are usually carried out on a large-scale and the quarry site is abandoned when the resource is depleted without site reclamation (Akanwa et al., 2017). According to Adekoya (2003) and Aigbedion (2005), farms within a close radius to quarries have a reduced crop output, which is attributed to dust pollution on crop leaves which disrupts the photosynthesis. Moreover, Oyinloye and Olofinyo (2017), also stated that, the natural photosynthesis can be disrupted when dust particles cover plant leaves which in turn cause the death of many plants near the quarry site.

2.4 Factors controlling the selection of optimal quarry site.

Quarrying involves crushing, blasting and excavating raw geological materials from the ground; hence this activity can cause pollution, noise and environmental impact in the vicinity of the quarry site. Therefore an appropriate measure has to be taken to locate suitable quarry sites that possess less environmental impact and good quality construction materials. In order to select suitable quarry site all factors controlling the suitability of the quarry site must be evaluated.

There are different factors that control the location of suitable quarry site. Some of these factors are rock type (the quality of rocks), topographic condition (slope angle and relative relief) of the site, population settlement condition of the site, land use/ land covers of the site, distance of the quarry site from the market, distance to water body, distance to build up area and overburden soil thickness of the site (Gudissa et al., 2020; Regessa et al., 2015).

2.4.1 Lithology

The characteristics of parent rocks play a major role in determining the quality of the produced aggregates (Engidasew, 2014) .Rocks have different physical and mechanical properties due to their texture, grain size and degree of weathering. Hence the type of rocks available affects the quality of the quarry product and suitability of the site. Therefore lithology is the most important factor influencing the quality of rock; for example; some flaky, soft, and friable rocks cannot be used as aggregate (Alkaradaghi et al., 2019).

2.4.2 Land use land cover

Quarry activity involves blasting, deforestation, excavation, crushing and transporting raw material. These activities results great effects on the socio-economic and environment. Therefore to assure the safety of the environment, heritage sites and human life it is important to consider the land use and land cover of the area, so as to control and avoid the impact of the quarry operation to both the environment and human life. The suitable potential quarry sites must be developed on the land use/land covers that are characterized by least damage potential to the land resources and landscape and that which have higher prospects for vegetation recovery and the resource of rehabilitation measures (Darwish et al., 2010). Accordingly environmental code of practices preserves and protects cultural heritage, archeological sites (Chabuk et al., 2017), parks, and built-up areas (Alkaradaghi et al., 2019). Thus, LULC may prohibit the development of quarry sites in these areas even when good quality and quantity material is available.

2.4.3 Distance to built up area

According to Guddisa et al. (2020), the community residing near to quarry sites experiences annoyance; nuisance, and sleep disturbance due to vibration, noise, fly rock, and dust caused by blasting during quarry operation. Quarries near to built up area generates severe dusts that can be felt about 100m from the source (Darwish et al., 2011; Maharaj et al., 2005; Subhasis et al., 2018).However quarrying can be possible with appropriate environmental protection and by adopting suitable mitigation measures (Guddisa et al., 2020). Therefore, to avoid noise and air pollution in the vicinity of built up area; adequate buffer zone has to be established. According to quarry code of practice (Tasmania, 2017), in areas where the material is crushed, only 750 m separations can be maintained.

2.4.4 Distance to water body

Runoff from quarry sites flows very rapidly towards nearby water bodies, thus lakes and streams are susceptible to pollution from quarries (Pal and Mandal, 2017). Therefore, it is important to develop the quarry operation at distance where the dust and runoff from the quarry cannot contaminate the nearby water bodies. The accumulation of the dust and rock aggregates from the quarry in channels can block the stream channels and disrupts the natural drainage system of the area. The runoff dissolves the waste particle from quarries which increases the total dissolved solid of the surface water. Therefore adequate buffer zone has to be established to avoid surface water pollution by quarry operation

2.4.5 Distance to roads

The distance of any rock construction material can affect both the economy of the project and the environment (Langer and Tucker, 2003) . According to Prentice (1990), the cost of transportation of aggregates doubles for every 10 miles road distance increment from source to the market. Roads at a far distance may result in additional project costs due to the development of new roads and increased transportation cost (Alkaradaghi et al., 2019).

In addition to economic importance of the quarry site being accessible to nearby roads also the safety of nearby roads from quarrying operation such as blasting which causes fly rocks, vibration and dust has to be evaluated. The proximity of the road to the quarry site may result in dangers of fly rock due to blasting and air pollution (Chabuk et al., 2017).

2.4.6 Overburden thickness

The thickness and nature of overburden material on the bed rock of the quarry can affect the economy and workability of the quarry product (Ragessa et al., 2015). According to Bell (2007), usually removal of overburden makes operations uneconomic. Therefore, during quarry site selection, the over burden thickness of the site and cost of removing should be considered as stripping overburden negatively affects economic exploitation (Bale, 2011; Magnusson et al., 2010). Regessa et al. (2015) suggested that overburden thickness of more than 4m unsuitable for quarry operation due to cost of operation. Nevertheless, according to importance of the overburden material further depth can be tolerated as overburden is used for fill material or other purpose.

2.4.7 Depth to groundwater

Solid particles from quarries and liquid wastes from lubricants and leaking fuels of heavy machineries can dissolve in water and percolate through fractures which results groundwater contamination in shallow aquifers. The removal of protective rock cover of aquifer and vibration from blasting during quarry operation can disrupt the existing fractures thus altering groundwater flow path (Ekmekci, 1990). The blasting activity widens fractures, thus, easing the percolation of contaminants to join shallow groundwater. Therefore quarries should be operated in areas were the groundwater is sufficiently deep.

2.4.8 Slope angle

The stability of the quarry site is to some extent governed by the slope angle of the area as areas with steep slope angle are prone to slope instability (Raghuvanshi, 2019), which may affect the workability and safety of the quarry site. The slope morphometry of a given area can be classified based on their slope angle as; escarpment/cliff ($>45^0$), steep slope (35^0-45^0), moderately steep slope (25^0-35^0), gentle slope (15^0-25^0) and very gentle slope ($<15^0$) slope angles (Anbalagan, 1992). Quarries located on steep slopes area commonly affected by environmental impacts such as soil erosion, rock falls and mass movements (Darwish et al., 2010).

2.4.9 Relative relief

Relative relief is the difference between the maximum and minimum attitudes within a certain cell (Oguchi, 1997). According to Alkaradaghi et al. (2019), relative relief is important from slope instability point of view, flooding potential, ease of excavation and inaccessibility. According to Guddisa et al. (2020), areas with relative relief of less than 5m are unsuitable for quarry operation due to its susceptibility for flooding and possess difficulty in excavation and areas with relative relief of more than 200m is less suitable for quarry site selection due to difficulty in accessibility and management.

2.5 Suitable quarry site selection in Ethiopia

Throughout the country a few works on suitable quarry site selection have been done. The work of Guddisa et al. (2020) and Ragessa et al. (2015) are among the recent researches on suitable quarry site selection in the country. Guddisa et al. (2020) have worked on the optimal quarry sites in Harer and Dire Dawa area, the study was conducted by adopting integrated GIS and Analytical hierarchy process (AHP) in which seven controlling factors of optimal quarry site selection were considered. These factors include lithology, land use and land cover, distance to built up areas, distance to water bodies, distance to roads, relative relief and slope angle. GIS-AHP based method was used by considering selected factors to produce the preliminary quarry site suitability map of the study area. Weighted overlay analysis in Arc GIS was used to overlay the thematic maps of all factors to generate the suitability map. The suitability map of the study area for all lithologies showed that 136 Km^2 (2.75%) of the area is highly suitable, 1587 Km^2 (32.11%) of the area is moderately suitable, 2166 Km^2 (43.83%) of the area has low suitability while the remaining 1053 Km^2 (21.31%) of land is unsuitable for quarrying. On the other hand Regassa et al. (2015) have used integrated GIS and geotechnical characterization to select the potential quarry site and characterize ballast rock for Ambo-Ijaji railway project in West Shawa zone of Oromiya region. In this study, six important parameters that may control the general suitability of the quarry site were identified. These parameters include slope, distance of the site, overburden soil thickness, land use/ land cover, general accessibility and rock type with its degree of weathering. The study covered 15km radius of the railway line and the study aim was only to locate suitable quarry sites for ballast rock supply to railway project.

2.6 Characterization of Crushed stone Aggregates

Crushed stone aggregate is the product of crushing rocks, boulders or large cobble stones, in which substantially all faces have resulted from the crushing operation (Langer and Knepper, 1998) . The sources of aggregates are either from bedrock or gravel and sand, the aggregates from bedrocks are acquired by means of crushing the bedrock using different tools and machines. The quality of the aggregates is controlled by property of the parent material (Hartley, 1974). Aggregates are used in production of cement and asphaltic concrete and it is the main input of Portland cement concrete and road pavement, therefore the quality of the aggregates has direct effect on the strength and durability of the concrete which in turn affects the good performance of the engineering structures.

Aggregate materials must be stable against breakdown in use and in stockpiles; free from joint flaws and micro-cracking; strong enough to with stand loading applied in use (both tensile and compressive); of low porosity and permeability in individual particles and chips; non-plastic; chemically inert in use, not coated with any substance nor polished to a degree where adhesion of bitumen or cement is adversely affected; and not deeply weathered (Dolar-Mantuani, 1983). The mechanical and physical properties of aggregates are commonly evaluated by using different laboratory testes (Waltham. 2002; El-Aal, 2015), such as aggregate crushing tests, aggregate impact tests, aggregate abrasion resistance test, aggregate water absorption, soundness, flakiness Index, elongation Index, specific gravity, density test, etc. Therefore to evaluate the quality of the aggregates laboratory test has to be conducted by adopting different test methods and specification. American Society for Testing and Materials (ASTM), American Association of State Highways and Transportation Officials (AASHTO), British Standards (BS) Indian standard (IS) and European Standards (UNIEN) specifications are commonly used standard test methods and specifications to characterize the aggregates for suitability of construction use.

Chapter Three

3. Materials and methodology

3.1 Methodology

The methods and approaches employed to conduct this study involve suitable quarry site selection using integrated AHP and GIS based approach, rock sample collection from selected areas, sample preparation and laboratory tests by adopting ASTM and BS standard aggregate test methods. Generally, the quarry site suitability map was generated by following approaches shown in figure1

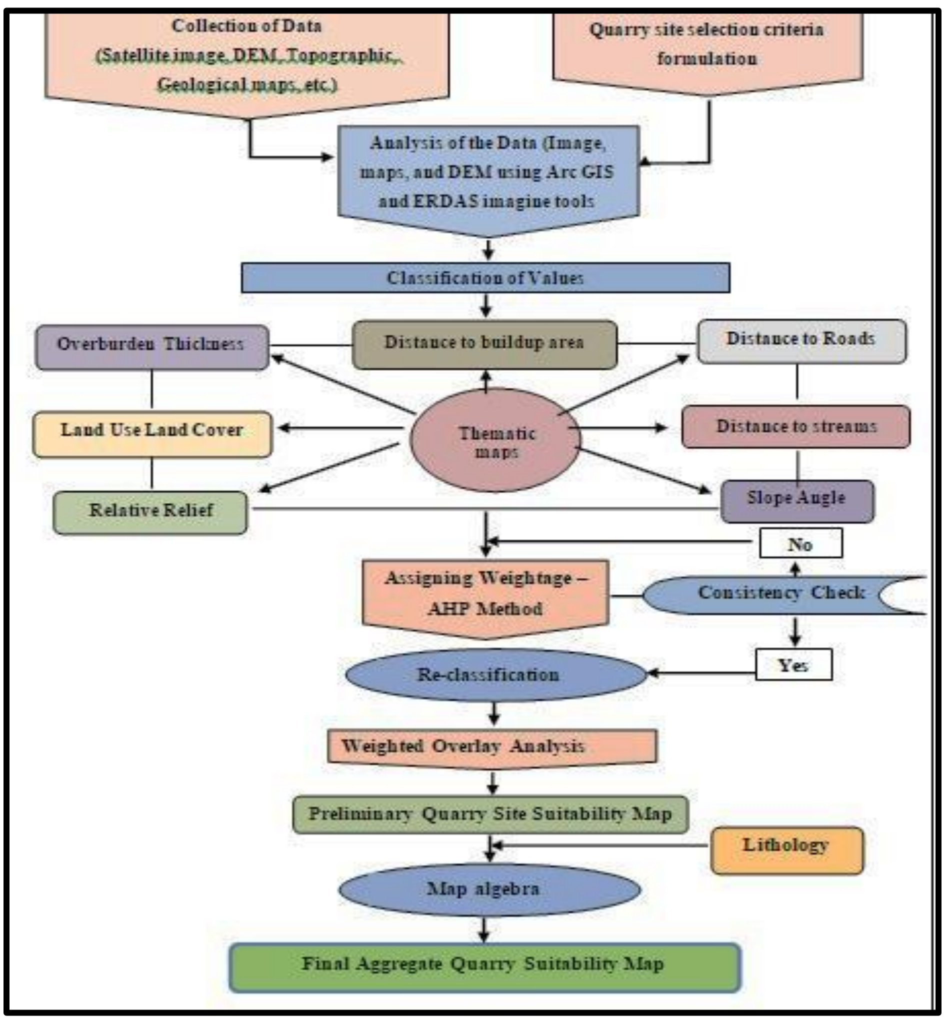

Figure 1 Flow chart showing procedures flowed to produce quarry site suitability map modified from Gudissa et al. (2020)

3.1.1 Data collection

The existing data relevant to this topic (literature) was thoroughly reviewed. All factors determining suitable quarry site is studied and materials needed to produce the thematic maps were collected. Geological map of Harer-Jigjiga (Scale of 1:250,000) by Workineh (2010) and subsheets of Hadaw and Gursum (scale 1:50, 000) by Abraham (2005), and that Of Jigjiga,Chinaksen and Lafaisa(scale 1:50,000) by Mulugeta and Yonas (2005) was gathered and used to produce the geological map of the study area. Landsat 8 image and Digital Elevation Model with 30m resolution was extracted from USGS Earth explorer and later processed to produce Land use land cover map, slope angle and Relative Relief map respectively. Jigjig area topo-sheet map with scale of 1:50,000 was collected from Ethiopian mapping Agency and the roads and buildup area was digitalized from it. All the existing borehole data was gathered mainly to obtain static groundwater level and the geological strata to now the overburden thickness throughout the study area.

3.1.2 Data Pre-processing

The selection of suitable quarry sites involves processing and classification of considered factors for optimal quarry site selection using Arc GIS. All the gathered data was processed, reclassified and assigned weight for each factors to produce quarry site suitability map using Arc GIS weighted overlay in spatial analysis tool.

The data for lithology was obtained from Harer-Jigjiga sheet (scale 1:250000) and sub sheets of Hadaw and Gursum (scale 1:50, 000) by and that Of Jigjiga,Chinaksen and Lafaisa (scale 1;50,000). The geological map of the study was prepared from these maps and later refined and corrected by conducting field survey. The digitalized geological map in vector format was converted to raster data and reclassified according to the suitability of the existing rock for construction material use.

Landsat8 image (Path 166, Row 53 and 54) with 30m resolution was extracted from USGS Earth explorer, mosaicked and used to prepare the Land use land cover of the study area. Supervised image classification was used in which more than 50 training samples were collected and maximum likelihood classification was employed to produce the land use land cover map.

Distance to road data was gathered from topographic map (1:50000) prepared by Ethiopian mapping Agency and Google earth images. Roads data obtained was clipped to the study area extent; projected to UTM zone 38 and raster conversion with 30 m resolution was done and later reclassified for suitable quarry site selection.

Distance to built up area was obtained from Topographic map and Google Earth images. The buildup area was buffered and Euclidian distance was computed with 30m resolution using Arc GIS to reclassify the buildup area for quarry site selection.

Distance to water body was extracted from DEM data because the area has no permanent river and lakes so that large stream was used as water bodies. The distance to large stream order was processed and reclassified for quarry site suitability.

Slope angle and relative relief was extracted from 30m resolution DEM data obtained from USGS Earth explorer, the data was projected to UTM zone 38 and reclassified for optimal quarry site selection.

The data for overburden Thickness was obtained from borehole data and by conducting field survey. The gathered points was fed and processed in Arc GIS; it is interpolated using IDW in spatial analyst tool and reclassified later for suitable quarry site selection.

3.1.3 Field reconnaissance survey

Before conducting detailed field work, ground reconnaissance survey was carried out mainly to produce geological map of the study area which is important factor controlling suitable quarry site selection. In this phase previously produced geological map of Harer-Jigjiga sheet by Geological Survey of Ethiopia at scale of 1:250, 0000 and that of Hadaw-Gursum; Jigjiga, Chinaksen and Lifaisa (sacle1:50,000) was used as base map and field work was conducted to correlate the lithology on the map with the existing lithology of the study area and lastly the geological map of the study area at scale of 1:50,000 was produced. The overburden thickness data points were gathered and later interpolated using Arc GIS IDW in spatial analyst tool.

3.1.4 Assigning weight using AHP method

Suitable site selection involves decision making by considering many alternatives which is difficult to decide without use of mathematical techniques. Analytical Hierarchy process is one of multi-criteria decision making process, which uses a mathematical technique to compute the best alternatives for decision making.

The AHP method has been developed by Saaty (1977) and has been adopted in previous works for a selection of groundwater recharge site (Rajasekhar et al., 2019), landfill site (Akanwa et al. 2017; Dimopoulou et al., 2013; Ebistu & Minale, 2013; Zelenović et al., 2012; Yoxas et al., 2011; Chabuk et al., 2016; 2017; Alkaradaghi et al., 2019; Khan and Samadder, 2015) and mining methods (Ataei et al., 2008; Mandal & Mondal 2016).

The major characteristic of the AHP method is the use of pair-wise comparisons which are used both to compare the alternatives with respect to the various criteria and to estimate criteria weights (Løken, 2007)

To compute the relative important of the factors considered pairwise comparison matrix has to be constructed. Each factor is given scale as rating. Usually rating between 1 to 9 is used as proposed by Satty (1977), the rating shows the importance of the factors considered over each other (Table1)

Table 1 Rating given to factors according to their relative importance (Satty, 1977).

Intensity of importance	Definitions	Explanations
1	Equally importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgment slightly favors one over the other
5	Much more important	Experience and judgment strongly favors one over the other
7	Very much important	Experience and judgment very strongly favors one over the other
9	Absolutely more important	The evidence favors one over the other is of the highest possible validity
2,4,6,8	Intermediate	When compromise is needed

The pairwise comparison matrix is constructed by AHP theory which states that if factor A is extremely important than factor B it is rated as 9 then B must be extremely less important than A and is rated as 1/9

In this study eight factors were considered for suitable quarry site selection, these are geological (lithology) land use land cover, distance to build up area, over burden thickness, distance to water, distance to road, relative Relief and slope angle. They are categorized as shown in table 2

Table 2 Factors considered in this study

Geological factor	Environmental factors	Economic factors
Lithology	Land use land cover	Overburden Thickness
	Distance to build up area	Distance to road
	Distance to water body	
	Relative relief	
	Slope angle	

Pairwise comparison of seven factors excluding lithology was constructed to compute the weight of each factor which later used for weighted overlay analysis in Arc GIS. Lithology was separately reclassified and later Math algebra product in spatial analysis tool of Arc GIS was used to extract areas with both suitable lithology for quarry site and suitable regarding the economic and environmental consideration for quarry site selection. The relative importance of the factors considered are justified in table 3

Table 3 Relative importance of factors considered in this study

S/n	Factors	Significance	Order of importance
1	Land use and Land cover	Environmental code of practices preserves and protects cultural heritages, archeological sites, parks and built-up areas. Thus, LULC may totally prohibit the development of quarry site even when good quality and quantity of a material is available.	Extremely strong influence
2	Distance to build up area	Dust and noise from crushers cause air and noise pollution to nearby communities hence quarries have to be far enough from built up areas	Very strong importance over the rest
3	Overburden Thickness	Removal of overburden material is very costly in developing quarry site. As a result, areas with less overburden material are preferred to be selected for quarry site selection	Strongly Important

4	Distance to water body	Dust and flying rocks from quarry sites cause the streams and surface water to pollute so that the quarry site has to be far enough from water bodies	Moderately more important
5	Distance to road	Distance to road plays a vital role in quarry site selection and it is mostly preferred that the quarry to be closer to road to reduce transportation cost but it has not to be close enough to avoid road damage and traffic jam	Least important but more important than Relative relief
6	Relative relief	It is important than slope angle as it controls flooding and easy of excavation	Moderately important than Slope angle
7	Slope angle	Highly steep slopes are associated with slope instability and triggers landslide although it is not the sole cause of landslide	Relatively least effect

Pairwise comparison matrix A (7x7) was constructed depending on the relative importance of the each factor as shown in table 4.

$$A= \begin{matrix} ai1 & a12 & aa1n \\ a21 & a22 & a2n \\ an1 & an2 & an3 \end{matrix} \quad aij= \frac{aij}{£aij} \quad \text{for i,j= 1,2.n}\text{---Eqn3.1}$$

The complete pairwise comparison matrix of the seven factors considered are shown in table 4

Table 4 Pairwise comparison matrix of seven factors

Attributes	LU	DB	OTH	DW	DR	RR	SA
LU	1	2	3	4	5	6	7
DB	½	1	2	3	4	5	6
OTH	1/3	½	1	2	3	4	5
DW	¼	1/3	½	1	2	3	4
DR	1/5	¼	1/3	½	1	2	3
RR	1/6	1/5	¼	1/3	1/2	1	2
SA	1/7	1/6	1/5	¼	1/3	1/2	1
Sum	2.59	4.45	7.28	11.08	15.83	21.50	28.00

After construction of the pairwise comparison matrix A, all the fractions are changed to decimal then matrix A is Normalized by dividing each column by the sum of the column, then Eigen vector or weight is calculated by averaging the sum of the rows.

Table 5 Normalized pairwise comparison metrics and calculated weight of each factor

Attributes	LU	DB	OTH	DW	DR	RR	SA	Eigen vector(w)	weight
LU	0.385654	0.449438	0.412088	0.361011	0.315856	0.27907	0.25	0.350445	35.04452
DB	0.192827	0.224719	0.274725	0.270758	0.252685	0.232558	0.214286	0.237508	23.75083
OTH	0.127266	0.11236	0.137363	0.180505	0.189514	0.186047	0.178571	0.158804	15.88035
DW	0.096413	0.074157	0.068681	0.090253	0.126342	0.139535	0.142857	0.105463	10.54627
DR	0.077131	0.05618	0.04533	0.045126	0.063171	0.093023	0.107143	0.069586	6.958626
RR	0.065561	0.044944	0.034341	0.029783	0.031586	0.046512	0.071429	0.046308	4.630783
SA	0.055148	0.038202	0.027473	0.022563	0.020846	0.023256	0.035714	0.031886	3.188615

After calculation of weights each factor the consistency of the matrix has to be checked if the Consistency ratio given by equation 3.3 is greater than 0.1 then the matrix is not consistent and it has to be randomly generated again (Saaty, 2008).

According to Saaty (1977), matrix of n such that Aw= λ max w for such matrix is said to be perfectly consistent if λ max=n. Generally the matrix is said to consistent such that λ max $\geq$n

Aw = λ max w ………………………………………………………………….......Eqn (3.2)

A= pairwise comparison matrix A

λ max=Maximum Eigen Value

W= Eigen vectors of matrix A or Weight of the factors

CR =CI / RI……………………………………………………………………….........Eqn (3.3)

CR= Consistency Ratio

RI is randomly generated number (consistency indices)

CI = (λ max – n)/ (n – 1)……………………………………………………………Eqn (3.4)

CI= Consistency Index

n= Number of factors computed

Table 6 Consistency indices(R) (Satty, 1977)

Matrix size(n)	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1,24	1.32	1.41	1.45	1.49

As shown in equation 3.2 to calculate λ max, Matrix A is multiplied by weights corresponding to each row.

For example, the product of matrix A and weight W for the first row of matrix A is calculated below

1*0.350445+2*0.237508+3*0.158804+4*0.105463+5*0.069586+6*0.046308+7*0.031886=2.572705. Completed product of AW is shown in table 7

Table 7 Product of matrix A and Eigen vector of each factor

Attributes	LU	DB	OTH	DW	DR	RR	SA	Aw
LU	0.350445	0.475016	0.476412	0.421852	0.34793	0.277848	0.223202	2.572705
DB	0.175223	0.237508	0.317608	0.316389	0.278344	0.23154	0.191316	1.747928
OTH	0.115647	0.118754	0.158804	0.210926	0.208758	0.185232	0.15943	1.157551
DW	0.087611	0.078378	0.079402	0.105463	0.139172	0.138924	0.127544	0.756494
DR	0.070089	0.059377	0.052405	0.052732	0.069586	0.092616	0.095658	0.492463
RR	0.059576	0.047502	0.039701	0.034803	0.034793	0.046308	0.063772	0.326454
SA	0.050114	0.040376	0.031761	0.026366	0.022963	0.023154	0.031886	0.22662

By rearranging equation3.2 λ max =Aw/W

Table 8 Ratio of AW and Eigen vectors (W)

Aw	W	Aw/W
2.572705	0.350445	7.341252
1.747928	0.237508	7.359447
1.157551	0.158804	7.289179
0.756494	0.105463	7.173074
0.492463	0.069586	7.077039
0.326454	0.046308	7.049625
0.22662	0.031886	7.107192

The maximum Eigen value λ max= average of Aw/W = 7.2

CI = $\frac{7.2-7}{6} = 0.033$

RI for Seven factors is 1.32 as shown in table 6

CR$= \frac{0.33}{1.32} = 0.025$

Table 9 weight of each factor with acceptable consistency ratio

Attributes	LU	DB	OTH	DW	DR	RR	SA	Eigenvector weights	Weights (%)
LU	1	2	3	4	5	6	7	0.350445	35
DB	½	1	2	3	4	5	6	0.237508	24
OTH	1/3	½	1	2	3	4	5	0.158804	16
DW	¼	1/3	½	1	2	3	4	0.105463	10
DR	1/5	¼	1/3	½	1	2	3	0.069586	7
RR	1/6	1/5	¼	1/3	½	1	2	0.046308	5
SA	1/7	1/6	1/5	¼	1/3	½	1	0.031886	3
Total Consistency Ratio (CR) 0.025 consistency is acceptable								1	100

3.1.5 Reclassification of thematic layers and weighted overlay analysis

The factors considered for suitable quarry site selection were classified; reclassified and rated according to their suitability for quarry site selection. The reclassification was done using Arc GIS reclassify tool in spatial analysis tools, by adopting pre-defined rating for each thematic layer. The classification of all factors for suitable quarry site is adopted from existing literature and modified for current study as described below and this rating is used to reclassify the thematic layer of each factor using Arc GIS. The reclassified thematic map is presented in chapter five.

Lithology is the most important factors for quarry site selection as it controls the availability, quantity and quality of the geological construction material. Lithology is classified according to the strength and suitability of the rocks for aggregate use, cohesive, fine grained basalt was considered as the most suitable for crushed aggregate and while massive fine grained limestone was rated next to basalt (Langer and Knepper, 1995; Leroy et al., 2017). Banded gneiss, Amphibolite and friable sandstone were classified as the least suitable rocks for crushed aggregates and Granite, Granodiorite and gabbro was selected as moderately suitable rocks. Non cohesive alluvium and eluvium deposit is unsuitable for crushed stone aggregates and are excluded.

Land use land cover map of the study area comprises settlement, dense forest, agricultural land, sparse shrubs and bare land. Settlements were selected unsuitable for quarry sites selection to protect the population form air and noise pollution, dense forest was selected as the least suitable for quarry sites to preserve the vegetation and bare land is the most suitable for quarry site section. Agricultural lands were considered to be moderately suitable as profit from quarrying can compensate that of agricultural product. The classification of land use land cover for quarry site suitability is presented in table 10

Quarries near to built up area generates severe dusts that can be felt about 100m from the source (Maharaj et al., 2005; Darwish et al., 2011; Tasmania, 2017; Subhasis et al., 2018). According to quarry code of practice (Tasmania, 2017) in areas where the material is crushed, only 750 m separations can be maintained. In the current study area, no blasting activity was encountered and areas with a proximity less than 750m was selected as unsuitable for quarry operation then every 250m new classification was established (Table 10).

Removal of overburden thickness is very costly as a result areas with less overburden thickness were selected as the most suitable for quarry site selection. The overburden thickness of study area was classified into 5 classes the classification was modified from that of Regessa et al. (2015) and (Gudissa et al., 2021) in which the areas with overburden thickness less than 1.5m was considered the most suitable for quarry site selection. An area with overburden thickness of 8m and above was selected as unsuitable for quarry site.

Run off from quarry sites flows to join nearby water bodies as a result the lakes and streams are susceptible to pollution from quarries (Pal and Mandal, 2017), thus adequate buffer zone has to be established around water bodies (Premasiri et al., 2016). In this study separation less than 150m from water bodies was considered unsuitable for quarry operation and separation of 750m and more was selected as the most suitable for quarry site selection

Proximity of the quarry to roads is important for economic and transportation of the quarry product, nevertheless ‘’area within 500m distance to existing rocks can easily be affected by dust, flying rock and vibration from quarry activity’’.(Guddisa et al,.2020 P.9). Following this, areas within 500m distance to road were considered unsuitable for quarry site selection. On another hand areas more 7500m from existing roads were selected as the least suitable sites due cost of transportation. Furthermore areas between 2500m-5000m is not close not far and was selected the most suitable site for quarry site.

According to Gudissa et al. (2020), areas with relative relief of less than 5m may be accessible for quarry operation however it usually susceptible for flooding and possess difficulty in excavation hence areas with relative relief <5m was considered unsuitable for quarry site selection. Furthermore areas with 200m and more were classed as the least suitable for quarry site selection due to difficulty in accessibility and management (Guddisa et al., 2020). Areas with 5-50m relative relief was considered as the most suitable sites for quarrying due its accessibility (Table 10)

Slope angle affects the stability of the quarry section. Generally the stability of the slope decreases as the slope height increases (Raghuvanshi, 2019). As a result areas with steep slopes were considered as the least suitable for quarry site selection. Slope angle not only control slope stability but also the affects the accessibility; operation flooding and drainage of the areas, hence areas with slope angle of $<5^0$ was considered unsuitable for quarrying due to poor drainage, waterlogging and difficulty in excavation (Table 10). Areas with slope angle of $5\text{-}15^0$ are neither very gentle nor very steep and are considered as the most suitable for quarry site selection.

Table 10 Classified factors for suitable quarry site selection modified from (Khan and Smadder, 2015; Regessa et al., 2015; Gudissa et al., 2020, 2021)

Factors	Description	Suitability	Rating	Factors	Description	Suitability	Rating
Land use land cover				**Lithology**			
Settlement	Housing, heritage sites and air field areas	Unsuitable	1	Alluvium and Elluvium products	Easily disintegrate and contains heterogeneous clay layers	Unsuitable	1
Dense Forest	Thickly vegetated land	Low	2	Sandstone, Gneiss and Amphibolite	Friable, Banded and flaky when crushed	low	4
Agricultural lands	Cultivated areas	Moderately	3	Granite, Granodiorite and Gabbro	Course grained, non-crushable.	Moderately	3
Sparse shrubs	Sparsely vegetated with small trees	High	4	Limestone	Massive and Easily crushed	High	4
Bare lands	No vegetation cover	Very highly	5	Basalt	Fine grained strong igneous rock	Very high	5
Distance to built up area (m)				**Over burden Thickness (m)**			
<750m	Very close	Unsuitable	1	>8m	Very thick	Unsuitable	1
750-1000m	Close	Low	2	4-8m	Fairly thick	low	2
1000-1250m	Intermediate	Moderately	3	2.5-4	Moderately thick	Moderately	3
1250-	Far	High	4	2.5-1.5	Thin	High	4

1500m							
>1500m	Fairly far away	Very high	5	0-1.5m	Very thin	Very high	5
Distance to water body (m)				**Distance to Roads (m)**			
<150m	Very close	Unsuitable	1	<500m	Very close	Unsuitable	1
150-350m	Close	Low	2	500-2500m	Close	Very high	5
350-550m	Intermediate	Moderately	3	2500-5000m	Moderately	Highly	4
550-750m	Fairly far away	High	4	5000-7500m	Fairly far away	Moderately	3
>750m	Fair away	Very high	5	>7500m	Far away	Low	2
Relative Relief (m)				**Slope Angle (^{o})**			
<5m	Very low	Unsuitable	1	<5	Extremely gentle	Unsuitable	1
5-50m	Low	Very high	5	5-15	Very gentle	Very high	5
50-100m	Moderately	Highly	4	15-25	Gentle	Highly	4
100-200m	High	Moderately	3	25-35	Moderately steep	Moderately	3
>200m	Very high	Low	2	>35	Steep	Low	2

The thematic maps of all factors were reclassified into five classes using Arc GIS reclassify in spatial analysis tool using the classifications discussed in Table 10 for suitable quarry site selection. The entire thematic layers were projected to UTM zone 38 with resolution 30m then the preliminary quarry site suitability map by considering the economic and environmental factors (7 factors excluding lithology) was generated using weighted overlay in spatial analysis tool in Arc GIS, however to extract areas with suitable lithology for aggregates and suitable for quarry site in term of economic and environmental aspect, Math Algebra tool in Arc GIS was used by overlaying the preliminary quarry site suitability map and reclassified lithology using Math algebra product. The area with both good in lithology and other economic and environmental factors was extracted and the final quarry site suitability map of the study area was produced.

3.1.5 Detailed fieldwork and sample collection

After selection of optimal quarry site by considering the governing factors, representative rock block samples were collected from rock outcrops of highly suitable potential quarry sites for further inspection of their petrography, engineering and chemical compliance. Rock samples not less than 40kg were collected from each site. In this stage intense field work was conducted, the geological, geomorphological and hydrogeological and overburden thickness condition of the area was identified. The geological map and overburden thickness of the study area was modified. The location of the areas from which the samples were collected area described in table 11

Table 11 Sample site description

Quarry no	Location		Lithology	Overburden thickness(meter)	Distance to the town
	x	Y			
1	270406	1028439	Fine to medium grained Limestone	Less than 1m	13km
2	270520	1021976	Fine grained grayish limestone	Less than 1m	17km
3	272577	1022904	Fine grained grayish limestone	Less than 1m	18km
4	264167	1032241	Fine grained whitish gray highly weathered limestone	Less than 1m	6km
5	268122	1029185	Medium to coarse grained limestone	Less than 1m	10km
6	249071	1032183	Fine grained Basalt	Less than 1m	8km
7	248631	1034721	Fine grained Basalt	Less than 1m	9.5km
8	249377	1033675	Fine grained Basalt	Less than 1m	9.8km
9	248347	1033278	Fine grained Basalt	Less than 1m	10.3
10	247592	1033120	Fine grained Basalt	Less than 1m	11km

3.1.6 Engineering geological characterization of aggregate

Rock blocks taken from the field was reduced to aggregates size by crushing to various sizes following the ASTM and BS standards to conduct the various aggregate tests to assess the quality of the aggregates for construction use. Upon completion of the sample preparation, a set of physical and mechanical tests was performed on the rock samples following ASTM and BS standards. In this study basalt and limestone rocks were collected from 10 sites quarry sites and physico-mechanical property tests such as specific gravity, particle shape(flakiness and elongation), bulk density, water absorption; aggregate crushing value (ACV), Los Angeles abrasion value (LAV), aggregate impact value, soundness tests and point load index was conducted. For mineralogical characteristics, a thin section was prepared and the texture mineralogical composition of the rocks was analyzed. Following the laboratory tests, the overall laboratory data was evaluated and the assessment of the suitability of the rocks towards using as construction materials was carried out with regard to the various standards.

3.1.6.1 Point load strength index

Point load strength index of rocks was conducted following ASTM D 5731 (1995). According to this test method the rocks samples either core or rock block and irregular lumps is placed between two conical platens and concentrated load is applied until failure occurs. In this study due to difficulty in core and rock block preparation irregular lump rocks was used to conduct the point load strength index of rocks. The objective of conducting this test was to convert the point load strength of the rocks to uniaxial compressive strength due to difficulty in sample preparation and availability of unconfined compressive strength test machine in the study area. The test samples was prepared in such way that D is between 30mm to 85mm; L >0.5D and the ratio of D/W is between 1/3 and 1 but should not greater than 1, where D is distance between the two contact points and L is the distance between the contact point and the nearest free point while W is width of the test sample see figure 2.

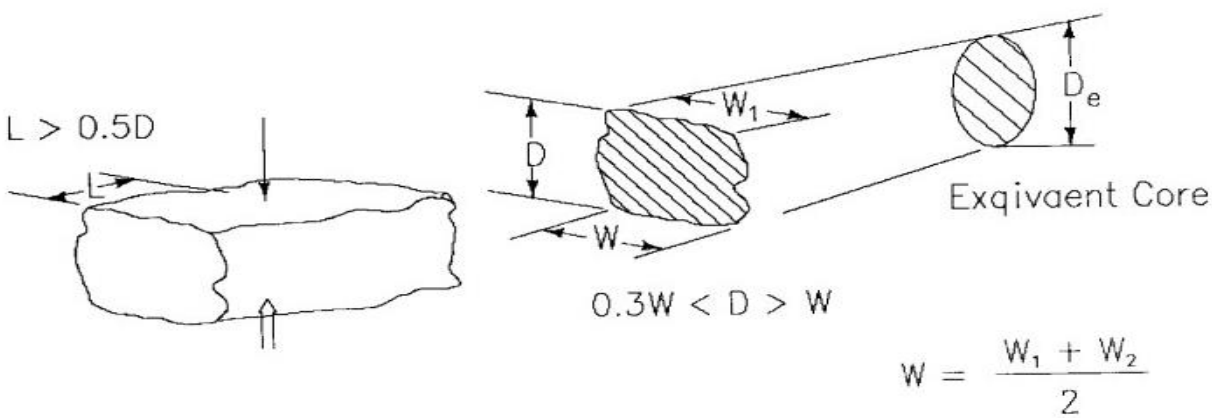

Figure 2Dimension required of irregular lumps for point load test ATM 5731 (1995)

According to ATM 5731 (1995) The point load strength index conducted over rock samples other than with core diameter of 50mm is Uncorrected point load strength index (Is) and has to be corrected to point load strength index of 50mm diameter Is(50) using correction factors F as shown in equation 3.6

$Is=P/De^2$……………………………………………………………………………..Eqn3.5

Is = uncorrected point load strength

P= failure load in N (newton)

$De^2 = 4A/\pi$ $De = \sqrt{4A}/\pi$

Is (50mm) = F*Is……………………………………………………………………..Eqn 3.6

Is (50) = corrected point load strength index

F= correction factor

$F = (De/50)^{0.45}$……………………………………………………………………….Eqn 3.7

In this study uncorrected point load strength index was obtained and converted to corrected point load strength index, finally using the corrected point load strength index unconfined compressive strength of rocks was calculated using equation3.8 forwarded by Broch and Franklin (1972).

UCS= 24*Is (50)……………………………………………………………….……Eqn3.8

Figure 3 Pont load test

3.1.6.2 Aggregates shape test

The aggregates shape test flakiness and elongation was conducted following BS 812-105.1 (1989) and BS 812-105.2 (1990) respectively. The flakiness was tested on material passing sieve 63m and retaining on sieve 6.3 and elongation was test on material passing sieve 50mm and retaining on sieve 6.3. samples was sieved and a test sample was selected from material retaining on sieve 50mm, 37.5mm, 28mm, 20mm, 14mm, 10mm and 6.3mm then the mass of each fraction and total mass was calculated (M1), the individual fraction with mass ≤5%of total mass was discarded and the remaining mass was recorded (M2) then material is passed over corresponding gauge size and the total material passing the gauge is recorded as the flaky particles (M3).

Flakiness index = $\frac{M3}{M2} * 100$..Eqn (3.8)

Where,

> M2 is the sum of the masses of size fractions that have a mass greater than 5% of the total mass; and M3 is the mass of all the flaky particles.

The elongation index test was conducted on material retaining on 37.5mm, 28mm, 20mm, 14mm, 10mm and 6.3mm, then the aggregates were passed over corresponding gauge size and the material not passing the gauge was recorded as the total elongated particles(M3).

Elongation index= $\frac{M3}{M2} * 100$...Eqn (3.9)

Where, M2 is the sum of the masses of size fractions that have a mass greater than 5% of the total mass; and M3 is the mass of all the elongated particles

Figure 4 Aggregate Shape test

3.1.6.3 Bulk density

The aggregate bulk density was carried out according to ASTM C 29/C 29M (2003). Following this test method the aggregates bulk density was calculated by filling aggregates passing 12.5 mm sieve in a container of a known volume and mass then the mass of aggregates in the container was measured and bulk density was calculated using equation 3.10. The bulk density test was conducted by rodding procedure, in this method the container is filled one-third with aggregates and the aggregate were stroke with 25 strokes of the tamping rod evenly distributed over the surface again the container is filled two-third by striking 25 strokes as above and finally the container is filled to overflow and the same procedure as mentioned above was done and the aggregate was leveled by finger to discard excess aggregates over the container.

$M = \frac{G-T}{V}$……………………………………………………………………………. Eqn 3.10

M= Bulk density

G= mass of the aggregate plus the container (Kg)

T= mass of the container (measure)

V= Volume of the measure (m^3)

Figure 5 Aggregates filled in container by striking with 25 strokes

3.1.6.4 Water absorption and specific gravity

The water absorption and specific gravity test was conducted in accordance with the ASTM C 127 (2001). According to this test method a test sample of minimum 2000gram from aggregates passing sieve 12.5 and retaining on sieve 4.75 was immersed in water at room temperature for 24 hours then the aggregates were removed from the water and rolled over absorbent cloth until all visible films of water are removed then the mass of saturated surface dry samples are weighted after the saturated surface mass is determined the sample are placed in wire basket and immersed in water container and its apparent mass in water was recorded, then the sample was oven dried at 110^{o}c for 24 hours, finally the samples is removed from the oven and the mass of oven dried sample was weighted. Lastly the water absorption and specific gravity was determined using equation 3.11 and 3.12 respectively.

$$water\ absorption = \frac{B-A}{A} x100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eqn\ 3.11$$

$$Specific\ gravity(SSD) = \frac{B}{B-c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn 3.12}$$

A= mass of oven-dry test sample in air, g,

B= mass of saturated-surface-dry test sample in air, g, and

C= apparent mass of saturated test sample in water, g.

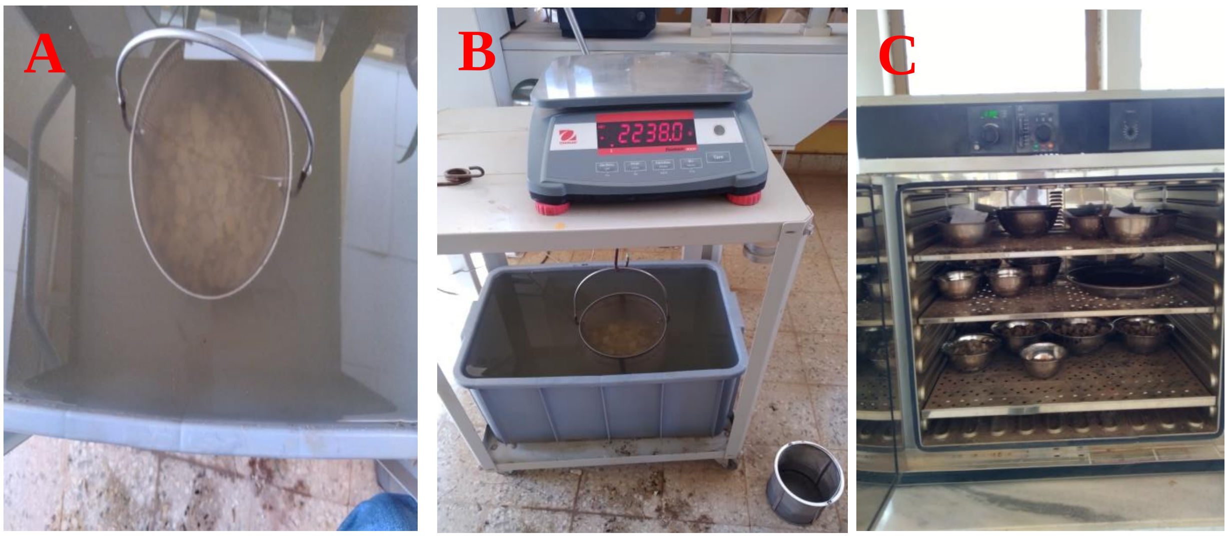

Figure 6 Aggregates soaked in water (A) Apparent mass (B) and Aggregates in oven(C)

3.1.6.5 Aggregate crushing value

The aggregate crushing value was conducted in accordance with BS 812-110 (1990). According to thius test method the test sample was obatined from aggregates passing sieve 14mm and retaining on 10mm then the mass of the sample was weighted and placed in cylindiral steel cup. The cup was filled one-third and the sample was struck with 25 random strokes by tamping rod from approximetley 50mm height then the cup is filled two-third and was struck with 25 random stroke and lastly it is filled and the above mentioned procedure was done. After the sample prepation is over the cup conatianing the sample was covered with plunger and placed in the compresion machine then gradual constant load was applied until 400KN was attained in 10 minutes, Finally the sample was removed and sieved over 2.36mm sieve and percenatge passing this sieve was recorded as aggregate crushing value as shown in Eqn 3.13.

$ACV=\frac{M2}{M1}*100$……Eqn (3.13)

Where, M_2 is the mass of the material passing through 2.36mm sieve and M_1, is the total mass of the test sample.

Figure 7 Aggregates filled in cylindrical steel cup (A) aggregate placed in compression machine

3.1.6.6 Aggreagte impact test

The aggregate impact value test was done following BS 812-112 (1990). Following this test method a test sample of aggregates passing sieve 14mm and retaining on sieve 10mm was prepared then the test sample was placed in a cylindrical cup of known mass by filling one-third and striking with 25 strokes by tamping rod again filling two-third and finally filling to overflow by following the same procedure as mentioned above. The mass of the cup containing the sample was weighted and placed at the bottom of impact machine. The impact machine comprises cylindrical cup at the base, metal hammer with mass of 13.5Kg dropping from adjusted height of 380mm see figure 8. After the cup containing the sample is placed at the bottom of the impact machine the hammer is lifted to the adjusted height and dropped to hit the sample for 15 times, finally the sample was removed from the cup and sieved over 2.36mm sieve and the percentage passing this sieve was recorded as aggregate impact value. Three trials were conducted and the average was taken to be the aggregate impact value.

Aggregate impact value = $\frac{M2}{M1} * 100\%$..Eqn (3.14)

Where,

M1 is the mass of the test specimen (in g); and

M2 is the mass of the material passing the 2.36 mm test sieve (in g).

Figure 8 Aggregates impact test

3.1.6.7 Aggregate abrasion value

The aggreagate abrasion value test was conducted as per the ASTM C 131 (2003) test method. Following this test method 5000gram of aggregate passing seive 19mm and retaining on seive 9.5 (grade B) consisting of 2500 gram of material passing siev 19 and retaining on seive 12.5mm and 2500gram of material passing seive 12.5 and retaining on seive 9.5 was prepared then the test sample was charged in the Los angeles abrasion machine together with 11 sphereical steep balls. The machine was started to rotate 500 revolution with speed of 30 to 33 relovution per minute after the completion of 500 revolution the sample was removed from the drum and seived over 1.7mm sieve and percentage passing this seive was recorded as aggregates abrsion value as shown in equarion 3.15.

$$AV = \frac{M2}{M1} * 100 \quad \text{..........Eqn(3.15)}$$

Where M1 is the total mass of the sample taken and M2 is the mass of the aggregate retained in 1.7mm sieve.

Figure 9 Aggregates loaded in abrasion machine (A) steel balls charged together with aggregates (B)

3.1.6.8 Sodium sulphate Soundness value

Sodium sulphate soundness test was conducted in accordance with ASTM C 88 (1999). According to this test a test sample was prepared as shown in table 12. The total mass and grading of the test sample used is recoded. The sodium sulphate solution was prepared by mixing one liter of water with 215gram of anhydrous sodium sulphate powder. The sodium sulphate solution was kept at room temperature for 48 hours before use. Each test fraction of sample was placed in container and soaked in sodium sulphate solution for 16 to 18 hours then the aggregates were removed from the solution and allowed to drain for 15 minutes and placed in oven at temperature of 110^{o}c for 4 hours, the process of immersion and oven drying was repeated until five cycle is completed then the aggregates were washed with tape water until the sample appeared clear from the salt, finally the aggregates were sieved over designated sieve size for each test fraction (Table 12) and the percentage passing was calculated then weighted average was calculated from percentage loss for each fraction and grading of the each fraction and finally the total of weighted average of each fraction was recorded as the soundness value as shown in equation 3.16.

Table 12 Grading and mass of test sample used to conduct soundness test

Passing sieve	Retaining on sieve	Mass required (gram)	Test sieve designated to sieve the aggregate after test
37.5mm	19mm	1500	16mm
19mm	9.5mm	1000	8mm
9.5mm	4.75mm	300	4mm

$$\text{Soundness} = \sum \text{percentage loss for each fraction} * \text{Grading of each fraction} \ldots \ldots \text{Eqn3.16}$$

Figure 10 Sodium sulphate powder (A) Aggregate immersed in sodium sulphate solution (B) Aggregate placed in oven (C)

3.1.6.9 Petrographic analysis

A petrographic thin section analysis was conducted to identify the mineralogical and texture of the rock samples selected from suitable quarry sites and to assess the existence of minerals prone to alkali-silica reactivity. The petrographic thin section was prepared and analyzed at Geological survey of Ethiopia.

3.1.7 Correlation of Physico-mechanical properties and mineral composition of aggregates

The correlation between physico-mechanical and mineral composition of the aggregates were run using SPSS statistical software. The relationship between aggregates physico-mechanical properties and mineralogical composition were correlated to understand how the physic-mechanical properties and mineral composition are related.

3.2 Materials

The materials utilized to conduct this study are:

- GPS for navigation, topographic map and geological map was used as a base map
- Landsat 8 image and digital elevation model
- Arc GIS, Global mapper, Google earth software.
- Sample bag; for collecting rock samples
- Geological hammer to cut rock samples.
- Note book; to record the field observation
- Unconfined compressive strength machine
- Los Angeles abrasion machine
- Impact test machine

Chapter four

4. Description of the study area

4.1 Location and accessibility

The study area is located in Jigjiga district which is located in the Eastern part of Ethiopia, which is the headquarter of Somali regional state. It can be accessed through the main asphalt from Addis Ababa, the capital city of Ethiopia, that pass through Hararge zone of Oromia region to Jigjiga town having approximate distance of 600Km. The study area covers area of 2131Km^2 and it is geographically bounded between the longitudes of 42° 33' 0'' E to 43° 0' 0''E and latitudes of 9° 0' 0'' N to 9° 40' 0''N (Fig 11).

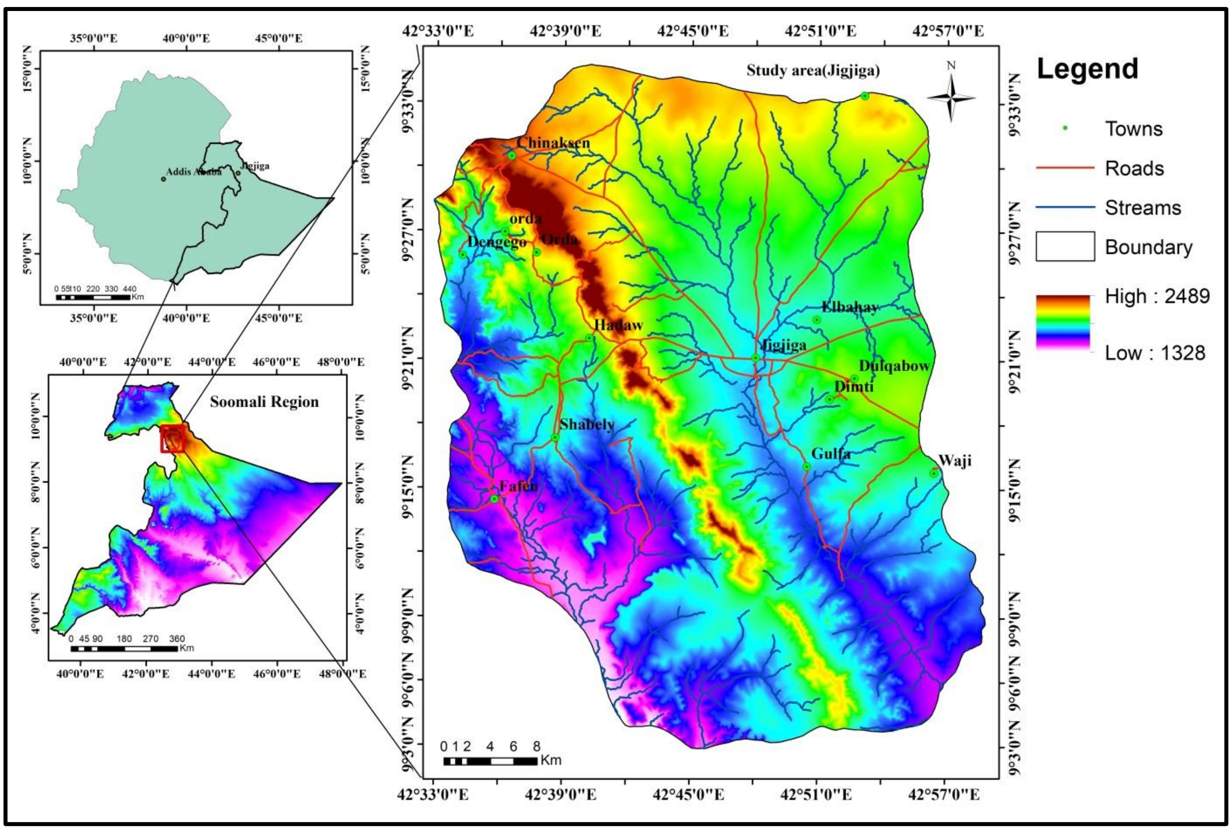

Figure 11 Location map of the study area

4.2 Physiography and topography of the study area

The topography of the area is characterized by mountainous, gentle sloping and flat lands. The elevation of the area ranges from 2489m to1328m above sea level. Most of study area, from Fafen to eastern part belongs to Shabelle basin and the western part from Chenaksen belongs to Awash basin (Ethiopian Mapping Authority [EMA], 1988). The western rugged topography and eastern gentle sloping flat lands are separated by Karamar mountain chains that run South-North direction across the study area, this land is highly elevated and some part densely vegetated.

Karamara Mountain is highest peak and is formed from tertiary basaltic volcanics (Workineh, 2010). The basaltic rocks are under laid by Hamanlie limestone and thin section of Jesoma sandstone. The western part is partially vegetated and characterized by rugged topography and comprises granitic and gneiss rocks and the eastern part is gentle sloping flat land, the area is mostly covered by quaternary Alluvial and limestone. The agricultural land covers the eastern, northern and some part of southern of the study area. Most of the southern east part is bare land and is covered by limestone and comprises the most suitable sites for quarry activity.

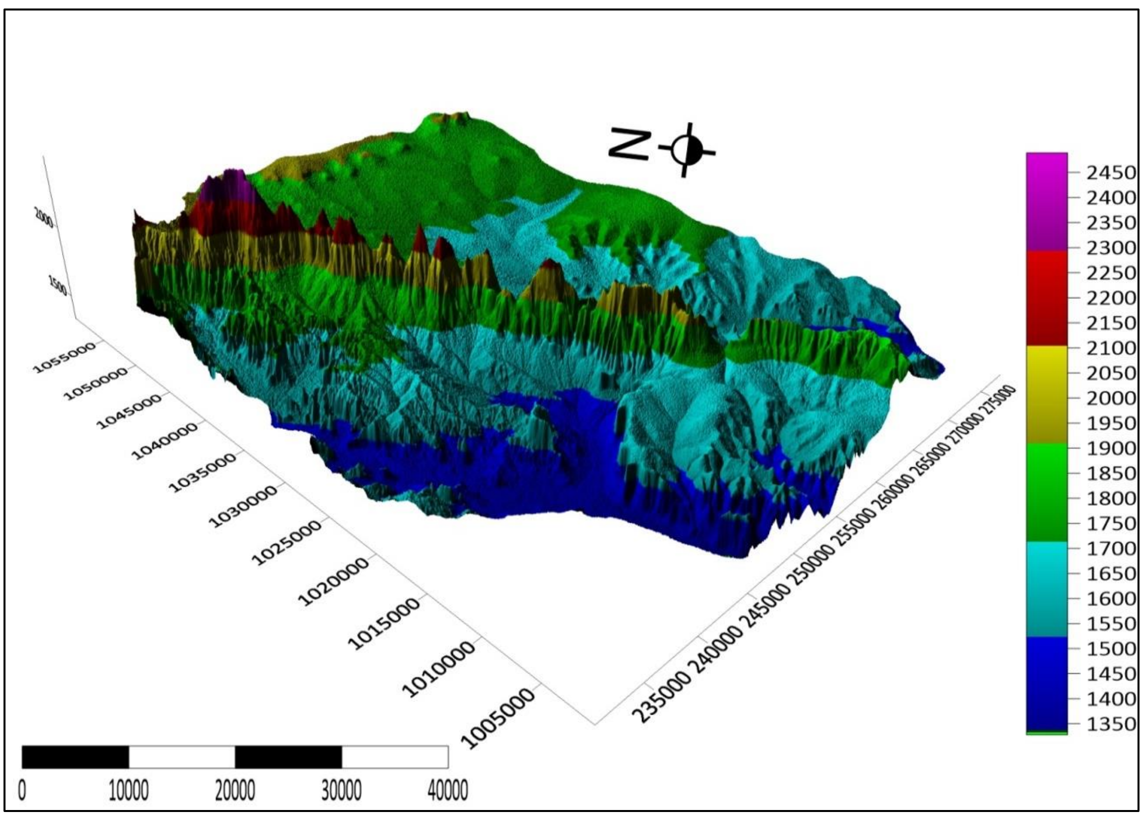

Figure 12 3D map of the study area

4.3 Climate

The Ethiopian climate classification provided by EMA (1981) is based on elevation in which areas above 3300m belong to Kur, areas between 1500-2300 belong to Dega, and areas between 500-1500 belong to Kolla, accordingly most of the study area belongs to Woina Dega and few areas forming highlands belong to Dega.

The study receives its rainfall during summer (kiremt), (June to September), According to 10 years rainfall and temperature data of the study area acquired from NASA (2022), the minimum and maximum annual rainfall of the area is between 569mm and 975mm with average annual rainfall of 756mm. The western part receives relatively more rainfall during June to September.

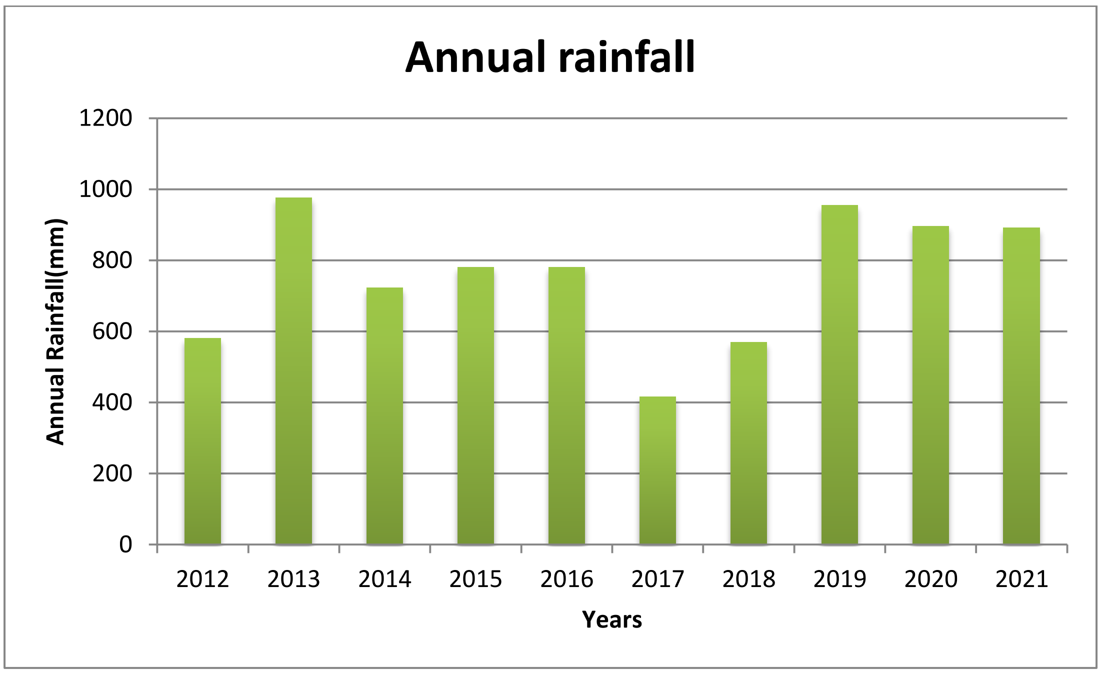

Figure 13 Annual rainfall of the study area

The minimum and maximum temperature of the area ranges between 9^{o}c to 35^{o}c the temperature raises between January and May. The area is characterized by cold night and sunny and often windy day.

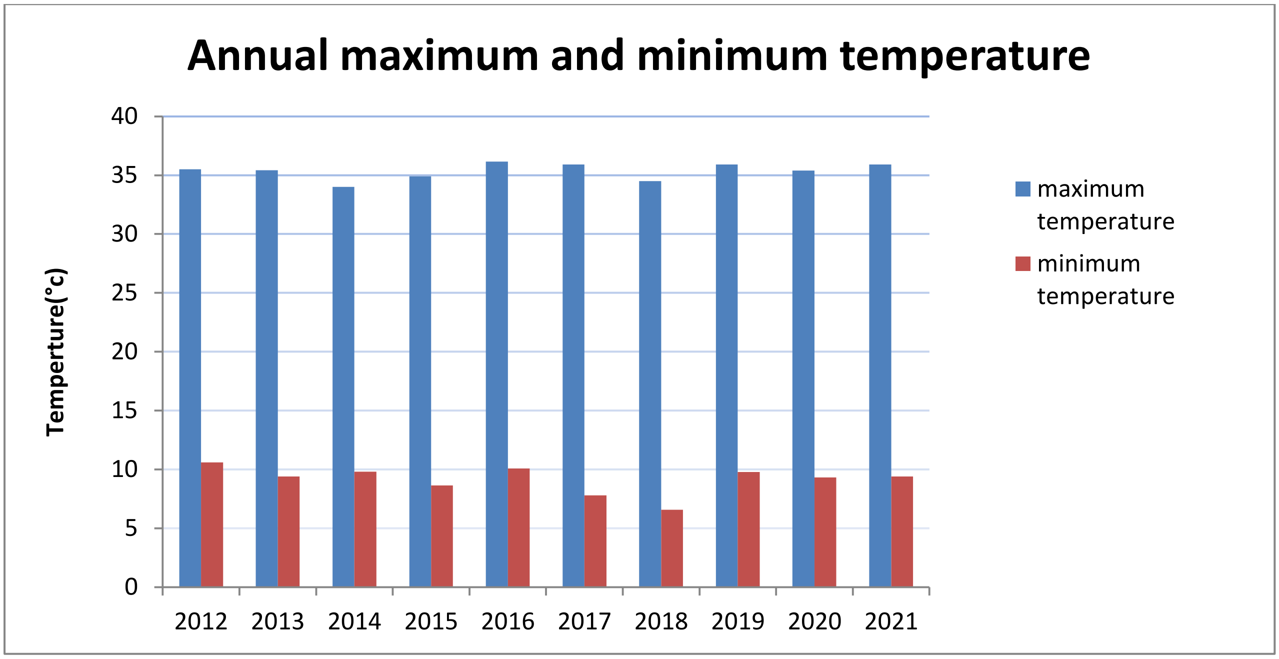

Figure 14 maximum and minimum temperature of the study area

4.4 Regional geological setting

The study area is located within Ogaden basin. The basin is situated in the southeast part of Ethiopia between latitudes of 4 and 8^{o}N and longitudes 40 and 48^{o}E and covers area of $350{,}000km^2$; it comprises late Paleozoic to tertiary sediments (Worku & Astin, 1992). The basin initiated from karoo rifting during Permian (Purcell, 1981), the event corresponds to the breakup of Gondwanaland (Norton & Sclater, 1979). According to Mège et al. (2015) in the Late Triassic to Early Jurassic, it turned into a sag basin, and marine waters from the newly opened Indian Ocean flooded the area, spreading to northern Ethiopia, and deposited 1,500 m or more of mostly carbonates and evaporates in a large shallow sea.

The geological, structural and stratigraphical understanding of the Ogaden Basin derives from oil exploration works which are commenced in the 1920s (Purcell, 1979). The geological map of Ethiopia (scale 1:2,000,000), first compiled by Kazmin (1972) and then revised by Tefera et al. (1996),constitutes an excellent reference material to have general lithological distributions and structural setup of the region. Furthermore, Purcel (1979), has studied the geology and petroleum potential of the basin. According to these studies currently the basin surface consists of Paleozoic to Neogene sediments, Precambrian basement and Cenozoic volcanic.

According to Purcell (1979) and Tefera et al. (1996),Mesozoic sediments are predominantly exposed in the western Ogaden while the recent Cenozoic sediments occur in the east, the contact of these lithology are associated with Marda fault zone (Mège et al., 2015).

According to Assefa (1988) and Purcel (1979), Calub Sandstone, Bokh Shale and Gumburo Sandstone comprises the Paleozoic sediments of the basin; Adigrat Sandstone; Hamanlie Formation; Uarandab Formation; Gabredahare Formation; Korahe Formation; Mustahil Formation; Ferfer Formation; Faf Formation and Belet Uein Formation comprises the Triassic to cretaceous sediments (Mesozoic sediments) while Jessoma Sandstone; Auradu Formation; Taleh Formation and Karkar Formation forms the tertiary sediments of the basin(Cenozoic sediments).

Table 13 Stratigraphy of Ogaden basin after (Purcel, 1979; Assefa, 1988)

Age		Lithostratigraphy	Lithologic Description
Era	Period		
Cenozoic	Tertiary	Karkar formation	Limestone with intercalation of marls, shale, and chalky limestone
		Taleh formation	Evaporitic unit containing, anhydrite, -;gypsum, dolomite, and clays
		Auradu formation	Biogenic limestone alternating with beds of chalky or gypsiferous limestone alternating with green to brown shale
		Jessoma formation	Fine to coarse grained sandstone and marls
Mesozoic	Cretaceous	Belet Uen Formation	Fossiliferous, sandy and cherty limestone with shale & gypsum. Marls, sandstone, & gypsiferous limestone also occur
		Ferfer Gypsum (Faf)	Grayish brown dolomite, shale, anhydrite, marl, interbeds limestone (equivalent to Amba Aradom Formation).
		Mustahil Formation	Limestone inter-bedded with shale and marls
		Gorahi Formation	Thickly bedded gypsum alternating with dolomite and thin limestone. It is also known as Main Gypsum Formation
	Jurassic	Gabredarre Formation	Light colored oolitic limestone, marls, & shaly limestone
		Urandab Formation	Sequence of dark shale, marl and gypsiferous limestone (equivalent to Agula Shale).
		Hamanlei formation	Densely cemented, bottom part fossiliferous, fine grained, grey to dark grey rock (equivalent to Antalo limestone).
	Upper Triassic	Adigrat sandstone	Fine to medium grained, sorted or non-sorted at places cross-bedded, yellow, reddish brown to white sandstone
Paleozoic	Permian	Gumburo Sandstone	Sandstone with overbank sediments
		Bohk Shale	Lacustrine shale, siltstone and minor sandstone.
		Calub Sandstone	Arkosic sandstone and lithic conglomerate and sandstone
Precambrian		Basement Rocks	Various basement rocks

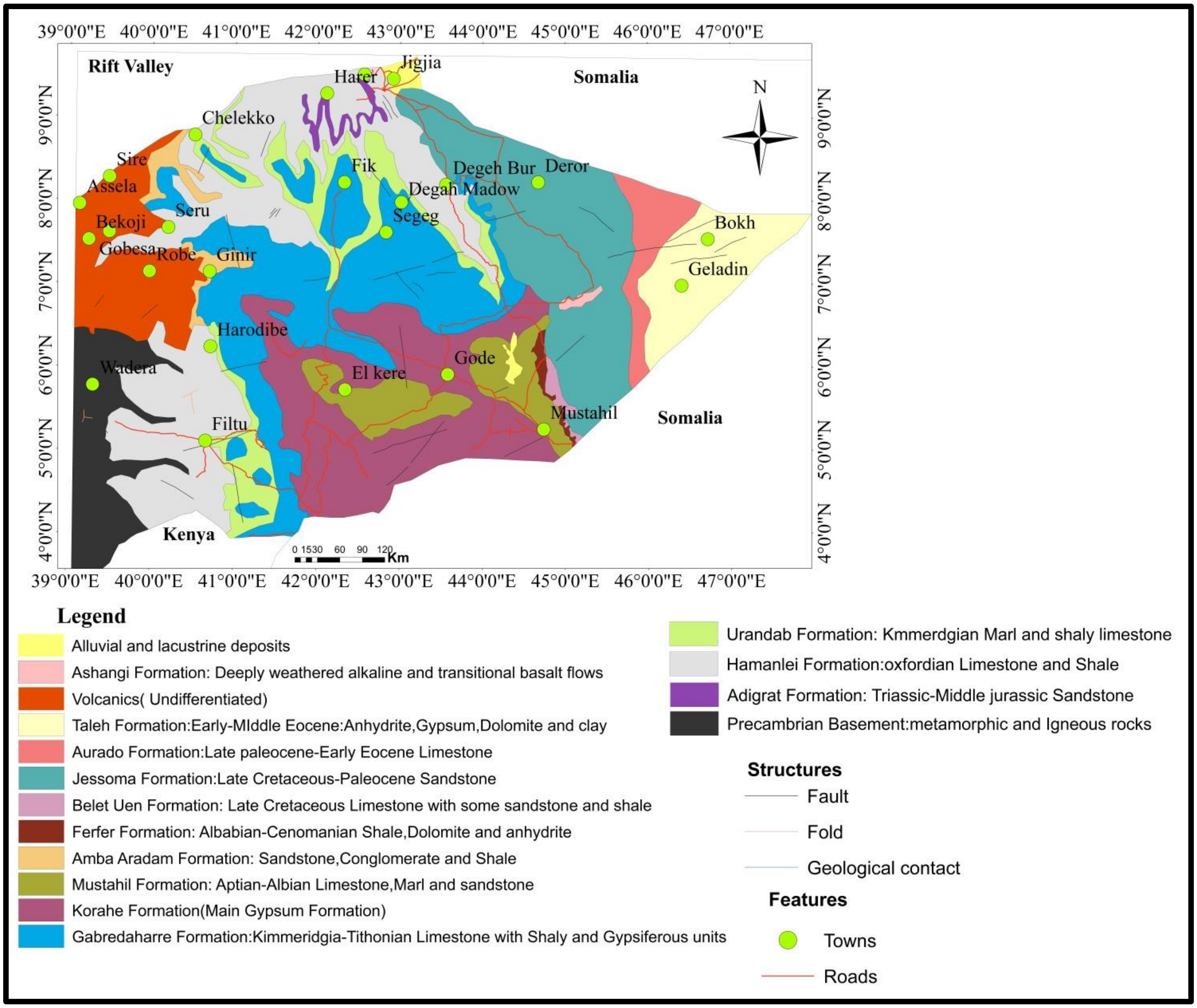

Figure 15 Regional geological map of Ogaden basin After Purcell (1979) and Tefera et al. (1996)

4.5 Local geology

The study area is located in northwest of Ogaden basin, the area was mapped by Abraham (2005), Mulugeta and Yonas (2005) and Workineh (2010) and compiled Sub-sheet of Gursum and Hadaw (1:50,000) sub sheet of Chenaksen, Lafaisa and Jigjiga(1:50,000) and Harer-Jigjiga map sheet (scale 1:250,000), respectively. According to these studies the surface of the study area comprises Precambrian basement, Mesozoic sediments, Cenozoic volcanic rocks and quaternary deposits. On the other hand fieldwork was conducted for current study mainly for ground truth confirmation and 1:50,000 scale map of the study area was produced.

The Precambrian rocks cover 16% of the study area, at the western part, lithologicaly they are represented by Amphibolite , Granite-gneiss, Granodiorite-gneiss, Doirite-gneiss, Gabbroic rocks, post- tectonic and syn- tectonics Granites. The Mesozoic sediments accounts 28% of the area and comprises limestone and sandstone according to Geleta (1998), the limestone in the study area are correlated to Hamenlie formation which is initiated in Jurassic.

Cenozoic volcanic rocks are exposed along Karamar mountain chain; they are mainly basaltic rocks and represents 8% of the mapped area. The quaternary covers account 48% of the study area and covers eastern part of the area. The geology of the study summarized from above mentioned maps and fieldwork observation is briefly discussed below.

4.5.1 Lower limestone

This unit is exposed in central and southern part of the study area; it covers 22% of the area. The lower limestone is unconformable and at places grades to the underlying lower sandstone. At places it is overlain with upper limestone and also with aphanitic basalt (Workineh, 2010). The unit is grey and fine to medium grained. The base of the limestone is usually fossiliferous calcarenites which is thickly bedded and grades upward to yellow marly limestone with beds of anhydrite and marls (Workineh, 2010). Micritic limestone is the major component of this unit (Abraham, 2005). The limestone is covered by thin less than 1m soil material, the over burden increases toward the west. The unit shows variable thickness and horizontally bedded. The thickness of lower limestone ranges from 85m-300m (Workineh, 2010). The limestone samples characterized for suitability of aggregates was collected from this rock unit.

Figure 16 Lower limestone in the study area

4.5.2 Upper limestone

The upper limestone stratigraphically overlays the lower limestone in the study area, the unit is exposed along the Karamara mountain chain and covers 5% of the area. The limestone of the upper sequence is thickly bedded often showing stylolites, their thickness varies from place to place and the maximum is about 200m (Workineh, 2010). It is comprised of various limestones such as micritic limestone with minor beds of dolomite, cherty limestone, black limestone and grainstone. The major component of this unit is micritic limestone it is creamy light to brownish gray and medium to thickly bedded, the unit forms gentle sloping ridges along Karamara Mountain. Petrographically, the limestone is composed of micrite 50-75% bioclasts 15-20%. The bioclasts include bivalves, brachiopods and forams with minor amount of oolites, pellets, intraclasts and dolomite (Workineh, 2010).

4.5.3 Lower sandstone

The lower sandstone underlays the lower limestone and is exposed at the base of karama mountain and eastern part of the study area near Jigjiga. The unit shows thickness of 2 m at Jigjiga area, it accounts 1% of the study area. The sandstone is horizontally bedded but in some places it shows cross bedding. Generally at the base the sandstone is coarse grained mature and well sorted but gradually the units changes to limestone at the top and laterally this unit becomes thinner at northwest of study area. The thin section of this unit shows varied sandstone types in at deferent beds such as arkosic sandstone, litharenite and rarely quartz arenite (Mulugeta and Yonas, 2005)

4.5.4. Plateau basalt

These volcanic rocks are tertiary basalt and cap the continuous limestone of Karama Mountain (Workineh, 2010). The unit covers the top part Karama Mountain and is locally called Karamara Basalt. Generally the basalt is grayish-black fine grained with columnar joints. The unit covers 7% of the area, mainly along Karamara Mountain. The unit is overlaid by thin less than 1m soil material. The Karamara lava has thickness of 186 and shows aphanitic, porphyritic and rarely amygdaloidal with columnar joints (Workineh, 2010). Porphyritic basalt sample taken from Karamara show 30-40% olivine, 10-30% plagioclase, 10% pyroxene, 10-15% opaque minerals. The matrix is 30-40% cryptocrystalline to glassy groundmass (Workineh, 2010).

Figure 17 Plateau basalt (Karamara Basalt)

4.5.5 Quaternary deposits

The quaternary deposits occupy the eastern and southern west of the study area, they cover 48% of the area and comprises; Quaternary Alluvium, Eluvium and caclcrete. The calcretes are poorly stratified calcilutites, interbedded with loose lime mud carbonate materials. At places they overlie soil horizon, which are in turn resting on marls or calcarenites of older ages (Workineh, 2010).

The Alluvium and Eluvium deposits overlay the limestone in the study area and shows thickness of more than 10 m and more along river channels. Generally they show various compositions of mainly gravel, conglomerate, silt and sand. Most of the areas that are covered by these deposits are agricultural lands.

4.5.6 Syn and post tectonic granite

These rock units are exposed around Hadaw and collectively cover 3% of the study area. The syn-tectonic granite is slightly deformed, less foliated and mainly composed of quartz, plagioclase, k-feldspars as well as minor amphibole minerals (Workineh, 2010). The granite is pinkish, medium to coarse grained, massive and slightly deformed.the post-tectonic granite is pinkish in color, coarse grained, and massive in texture. In outcrop plagioclase, k-feldspar, quartz as well as white mica are the major composition. In thin section this granite depicts k-feldspar 45%, plagioclase 30%, quartz 20%, & biotite 3% with traces of epidote and accessory minerals including sphene, opaque, muscovite, and hornblende (Workineh, 2010).

4.5.7 Amphibolite

The amphibolite is exposed at the west of the study area and cover 1% of the study area. Generally the rock unit is grayish black, medium grained, massive to strongly foliated and gneissose. Petrographic study of the amphibolite shows 58-70% amphibole, 8-15% plagioclase 10-20% quartz, 10% biotite 3% opaque minerals and 10% k-feldspar. Sphene, chlorite, epidote and carbonate represent secondary minerals (Workineh, 2010).

4.5.8 Gabbroic rock

The gabbroic bodies are exposed at the west of the study area; the unit covers 1% of the area. Gabbroic rocks are dark gray, medium to course grained and massive in texture with variable abundance of mafic minerals, at some places it shows deformation fabrics and pegmatite dykes (Abraham, 2005 and Workineh, 2010). Samples from Orda and Gebi Gebo localities show composition of 66-80% hornblende, 11-20% plagioclase, 8% quartz 3% opaque minerals and trace amount of biotite & k-feldspar; chlorite, & carbonate (Workineh, 2010).

4.5.8 Diorite Gneiss

Diorite gneiss is dark gray, course grained and massive in texture and is exposed along Fafen-Jigjiga road. The unit covers 4% of the study area. In the Fafem areas it is associated with amphibolite, amphibole schist and gabbroic bodies (Workineh, 2010). Thin section study of rock samples from dioritic gneiss depict composition of 35-36 % amphiboles, 6-20% biotite, 20-30% plagioclase 5-10% quartz 3% k-feldspar, 3% sphene, 6% opaque and traces of magnetite (Workineh, 2010).

4.5.9 Granodioritc Gneiss

This rock unit is exposed in the western portion of the research area and makes up 94 km2 (4%) of the total study area. Granodioritic gneiss is dark grey, medium grained and shows pronounced compositional banding of dark (mafic) and lighter minerals. The mafic minerals are biotite and amphibole, while the lighter ones are quartz and feldspars. Samples of granodioritic gneiss consist of quartz 26-36%, plagioclase 30-40%, quartz 12-25%, biotite, 5-15%, k-feldspar and 10% muscovite (Workineh, 2010). According to Workineh (2010), the unit also contains trace amounts of opaque, sphene, zircon and epidote also occur.

4.5.10 Granite Gneiss

Granitic gneiss is exposed at the vicinity of Hadaw and Northern Jigjiga and covers 58 km. sq, (3%) of the total area; the unit is pinkish gray; medium grained and show pronounced deformational fabrics. Granitic gneiss show east-west and north dipping compositional layering & display composition of, 18-25% biotite, 20-30% quartz, 25-30% plagioclase, 20-40% k-feldspar (microcline), 5% muscovite and traces of opaque & zircon (Workineh, 2010).

4.6 Geological Structures

According to Workineh (2010), the study area is characterized by presence of bedding planes, columnar joints, foliation, faults and shear zone. The Mesozoic limestone is characterized by horizontal bedding planes and Cenozoic basaltic rocks shows columnar joints.

The Precambrian rocks are affected by deformation events which resulted, NNW, ENE and N-trending composite foliations, shear planar fabrics and intrafolial folfds (Abraham, 2005). According to Workineh (2010), the shear zone occurs in high grade metamorphic rocks and is the result of numerous parallel NW-SE trending faults that formed in the late Precambrian.

The high grade metamorphic rocks shows gneissosity banding while, the lower grade metamorphic rocks are characterized by schistosiy. The ridges extending from the Karamara to Goro regions have older Cenozoic (Oligocene) fault, which produced lava flows (Workineh, 2010). The faults is known as Marda fault Belt (Kazmin, 1972; Black et al., 1974; Merla et al., 1979; Senbeto and Maarten, 1981; Tefera et al., 1996). The Marda Fault Belt has a NNW-SSE trend and passes southwest of Jigjiga town (Workineh, 2010).

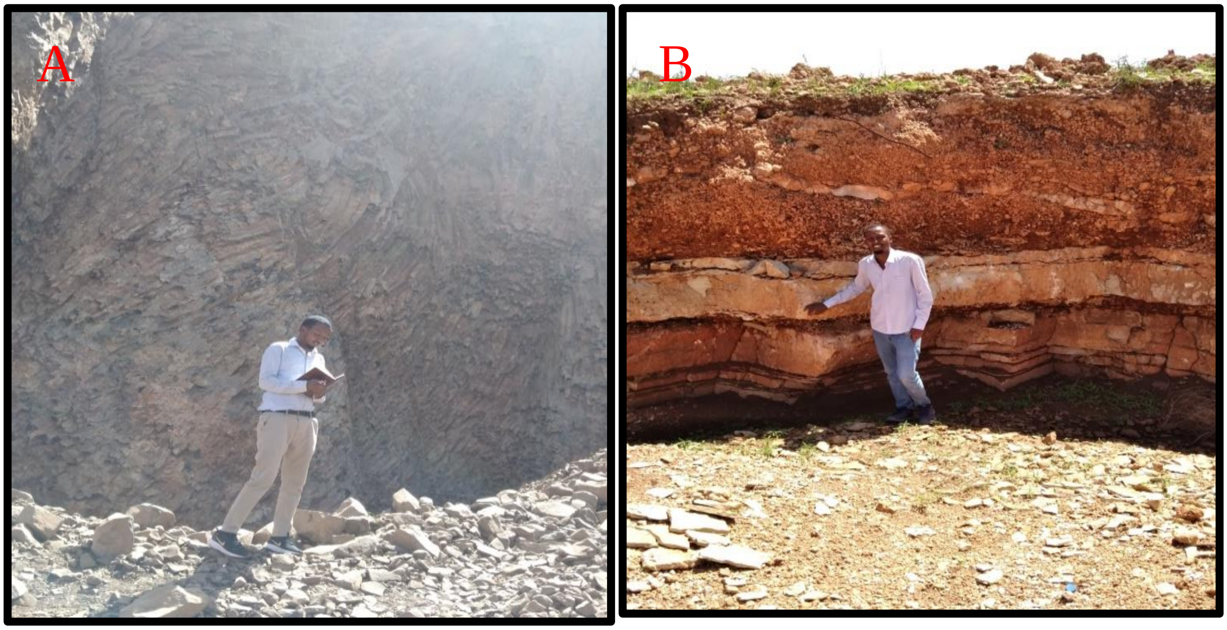

Figure 18 Columnar joint (A) and Bedding planes (B)

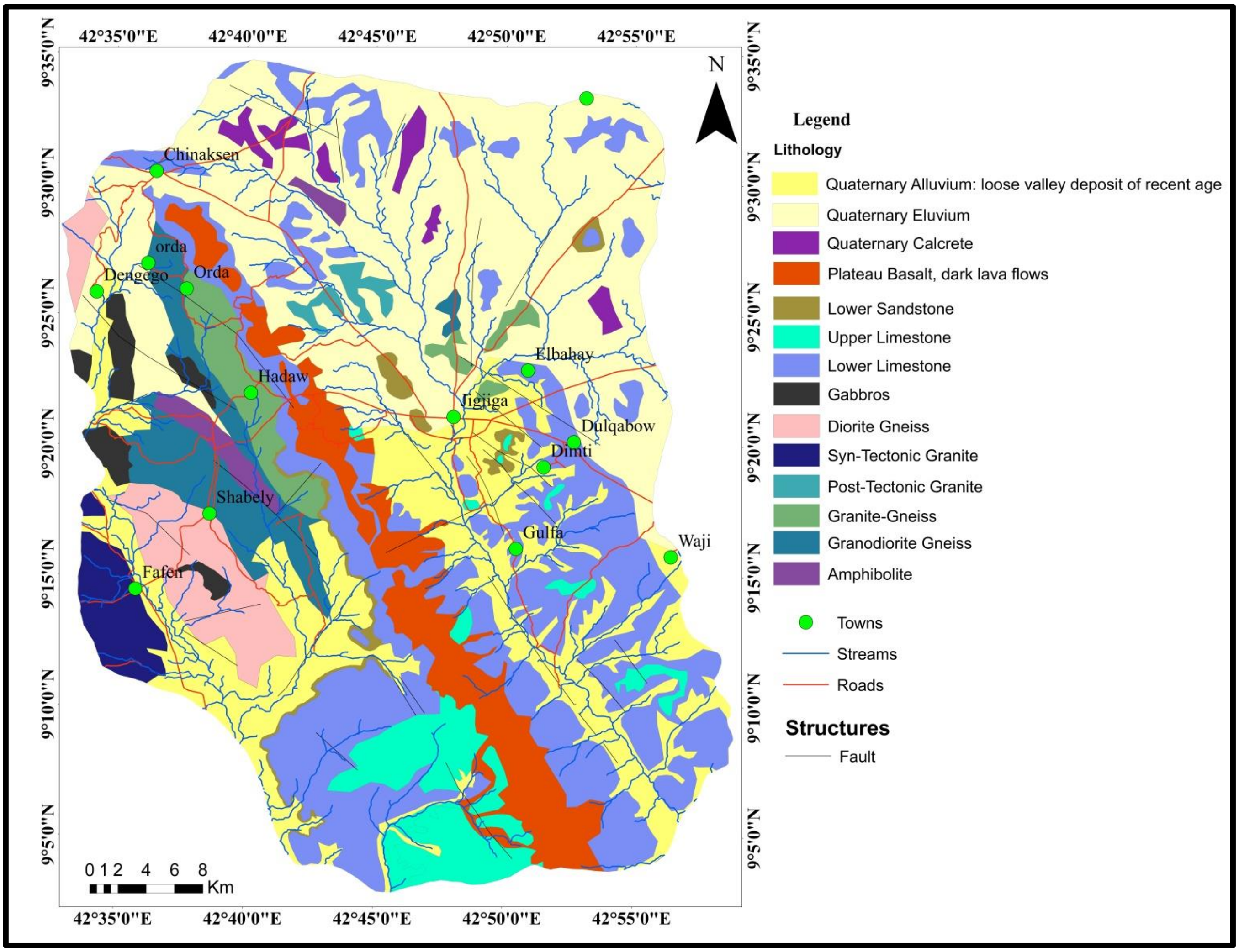

Figure 19 Local geological map modified from Abraham (2005), Mulugeta and Yonas (2005) and Workineh (2010).

Chapter five

5. Result and discussion

5.1 Reclassification of criteria for suitable quarry site selection

The criteria for suitable quarry site selection were classified and evaluated based on their suitability for quarry site selection, the considered criteria for suitable quarry site selection include lithology, land use land cover, distance to build up areas, overburden thickness, distance to water bodies, distance to roads, relative relief and slope angle. Each criterion was classified in to five sub classes based on its suitability for optimal quarry selection. Each sub class was given a rating, in this study rating between 1 and 5 was used (Table 10).These criteria and their classification and rating based on their suitability for quarry operation are discussed below:

5.1.1 Lithology

Lithology is the most important factor for quarry site selection as it controls the availability, quantity and quality of the geological construction material .The lithology of study area was reclassified into five classes. These are: (i) Basalt, (ii) Limestone, (iii) Granite and Gabbro (iv) Sandstone, Gneiss and Amphibolites, (v) Alluvium and Eluvium deposits. The lithology was classified based on their strength and suitability for aggregate use, cohesive, fine grained basalt is mostly considered as the most suitable for crushed aggregate while massive fine grained limestone is rated next to basalt (Langer and Knepper, 1995; Leroy et al., 2017). Banded gneiss, Amphibolite was considered as least suitable for aggregate due to their banding which results more flakiness when crushed (Bell, 2007) and sandstone was classified in this class due to its friability. Granite, granodiorite and gabbro were selected as moderately suitable rocks. Unconsolidated alluvium and aluvium deposits are unsuitable for aggregate use (Gudissa et al., 2020).Thus following this classification (Table 10) reclassified lithology for suitable quarry site was produced for current study. Based on the reclassification total area of 154.5 km^2 (7.2%) is covered by basalt which is very highly suitable for aggregate and the limestone covers area of 582.4 km^2 (27%) these rocks collectively cover 34.6 % of total study area (2132 km^2 .The unsuitable alluvium and aluvium deposits cover 48.7% of the area and the least suitable sandstone, gneiss and amphibolite for aggregate cover 12.6%. The moderately suitable granite and gabbro cover 4% of the study area.

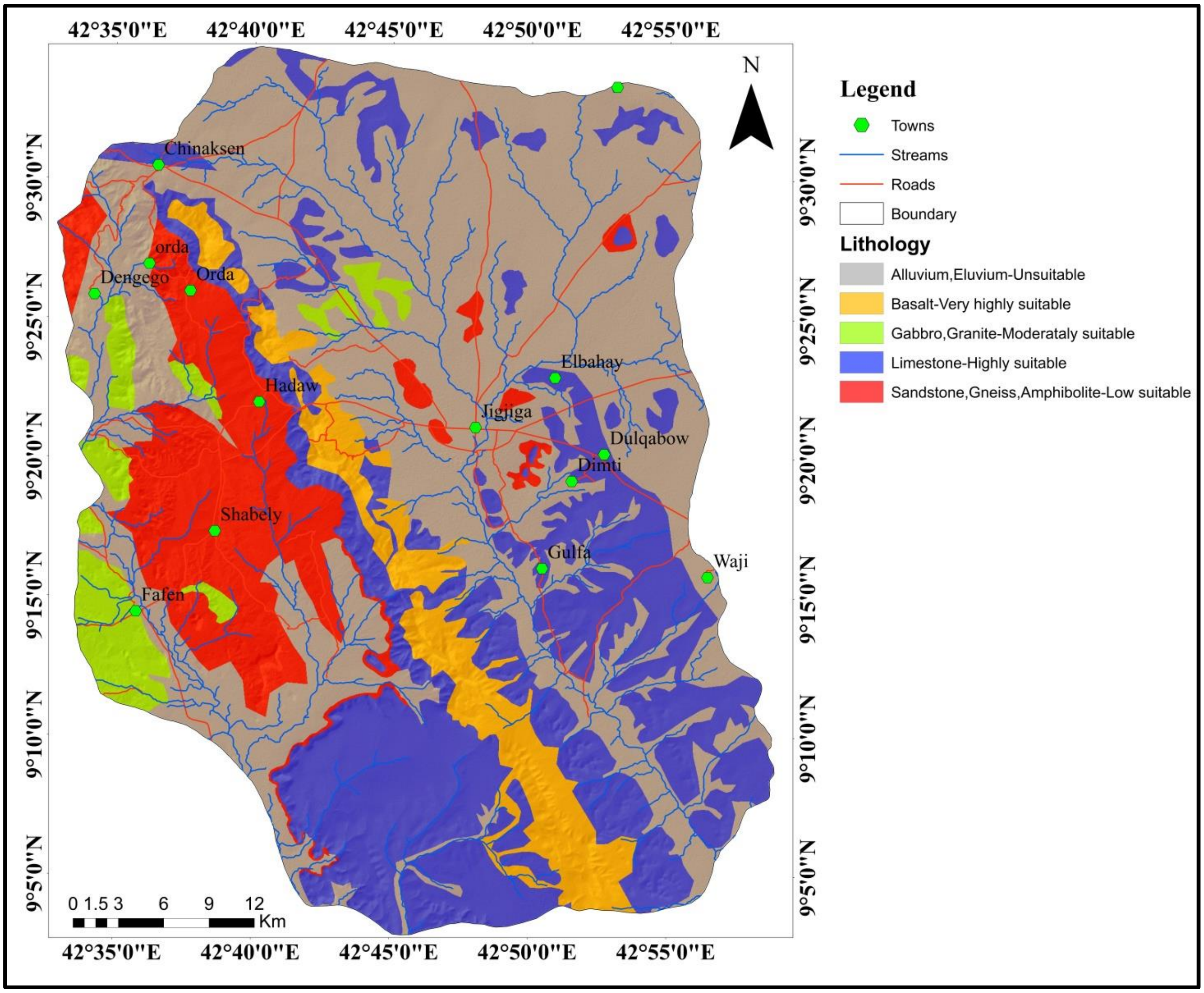

Figure 20 Reclassified Lithology map

5.1.2 Land use land cover

Maximum likelihood supervised image classification was used to produce the land use land cover map of the study area. Land use land cover map of the study area comprises settlement, dense forest, agricultural land, sparse shrubs and bare land. The suitable potential quarry sites must be developed on the land use/land covers that are characterized by least damage potential to the land resources and landscape and that which have higher prospects for vegetation recovery and the resource of rehabilitation measures (Darwish et al., 2010). Accordingly settlements and airfields were selected as unsuitable for quarry sites selection to protect the population form air and noise pollution, dense forest was selected as least suitable quarry sites to preserve the vegetation and bare land is the most suitable for quarry site selection. Agricultural lands were considered to be moderately suitable as profit from quarrying can compensate that of agricultural product. The classification of land use land cover for quarry site suitability is shown in (Table 10). Unsuitable settlement areas account 5.4% of the study area (114.6 km^2), dense forest represent 0.3% of the area and is found along Karamara Mountain. Agricultural land cover total area of 1137.3 km^2 (53.4%) while sparse shrubs and bare land collectively covers area of 872.6 km^2 (40.9%) of the study area and are highly suitable for quarry site.

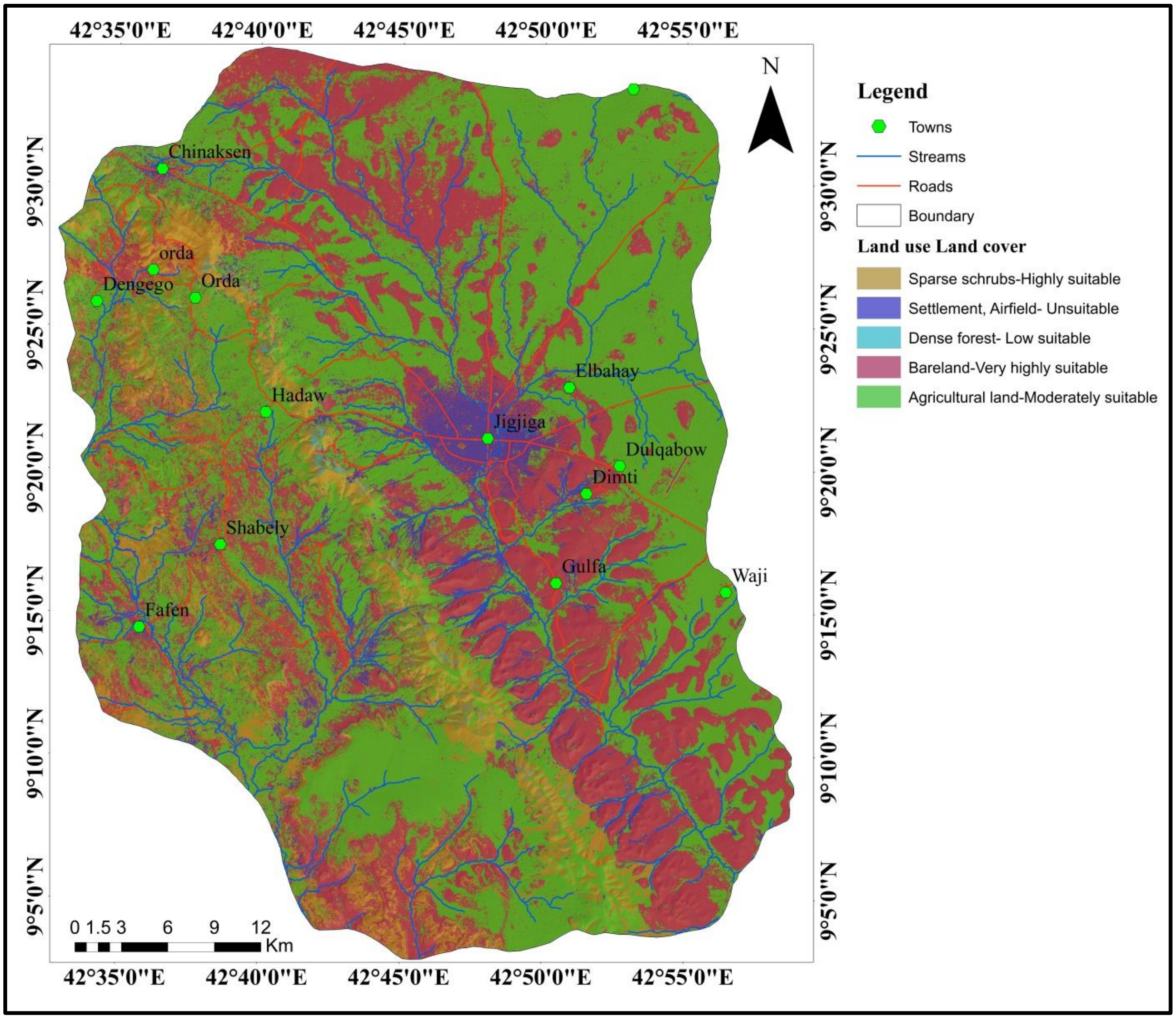

Figure 21 Reclassified land use land cover

5.1.3 Distance to built up area

The Communities residing near to quarry sites experiences annoyance; nuisance, and sleep disturbance due to vibration, noise, fly rock, and dust caused by blasting during quarry operation (Gudissa et al., 2020). Thus adequate buffer zone has to be established to protect the community from air and noise pollution associated with quarrying operation. According to quarry code of practice Tasmania (2017), in areas where the material is crushed, only 750 m separations can be maintained. For current study only crushing was encountered and areas within 750m distance form build up sites were considered unsuitable for quarry operation and every 250m new class was established (Table 10). For current study environmental concerns associated with quarrying is considered and the suitability was based on the distance of the quarry from built up areas. Thus as the distance of quarry from built up area increases the suitability increases although further distance increases transportation which in turn makes the quarry unsuitable. Nevertheless areas within 30Km distance from the project area was considered economically viable and the current study area is within 30Km radius of Jigjiga town. Thus for current study distance to buildup area was reclassified into five classes based on the relative suitability of each sub class for suitable quarry site selection.

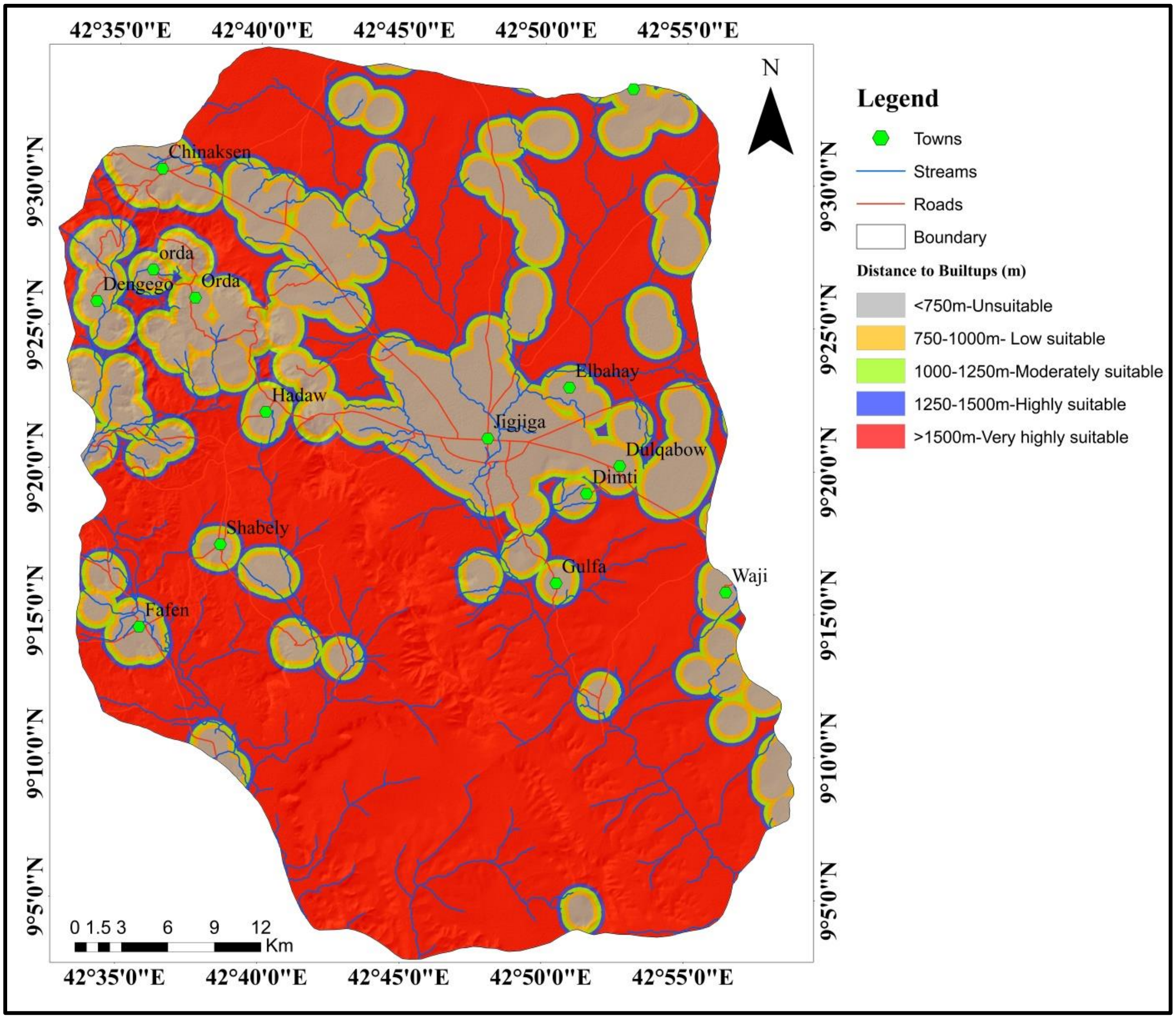

Figure 22 Reclassified Distance to built up area

5.1.4 Overburden thickness

The removal of thick overburden material affects the economics of the quarrying (Bell, 2007). To avoid excess expenses in removing overburden material, areas with low overburden thickness were chosen as appropriate quarry sites. According to Regessa et al. (2015), areas with overburden thickness of less than 1.5m are the most suitable sites for quarry operation. The overburden thickness of more than 8m is very low suitable for quarry site (Regessa et al., 2015; Gudissa et al., 2021). The overburden thickness of the study area ranges from 0.3m to 10m, southern east part of the area is covered with thick alluvium deposits. The borehole data from northern west area shows overburden thickness of 10m. For the current study the overburden thickness was reclassified into five classes based on their suitability for optimal quarry site selection (Table 10). An area with overburden of less than 1.5m was selected as the most suitable sites and areas with 1.5m-2.5m overburden was rated next to it. Areas with overburden of 2.5-4m was rated as moderately suitable and areas with 4-8m overburden thickness was considered as the least suitable sites , while the areas with overburden thickness of more than 8m was selected unsuitable for optimal quarry site selection (Fig 23). The reclassification was modified from that of and Regessa et al. (2015) and (Gudissa et al., 2021).

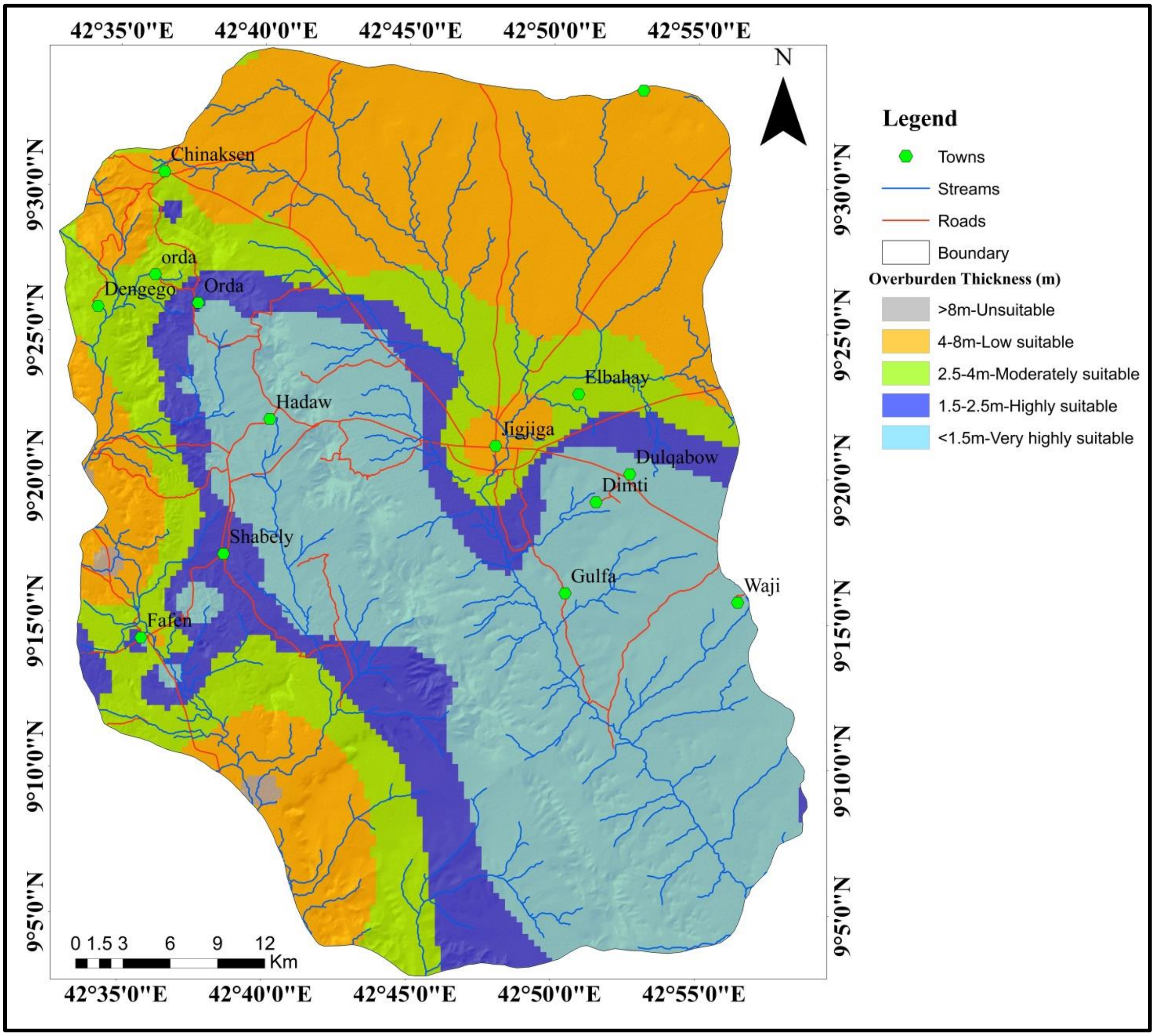

Figure 23 Reclassified overburden thickness map

5.1.5 Distance to water bodies

Effluents from quarries can greatly contaminate the nearby water bodies, thus adequate buffer zone has to be established around water bodies to avoid surface water contamination by quarries (Premasiri et al., 2016). Quarry sites within 150m distance from water bodies are close to water bodies (Kontos et al., 2005; Yoxas et al., 2011) and may contaminate the streams due to effluents from the quarry activities (Gudissa et al., 2020). However, a quarry site that is more than 600 m from water bodies is quite far away, and pollution from the quarry's operations may be controlled (Gudissa et al., 2020). For current study distance to water bodies was reclassified into five classes (Fig 24).Areas within 150m distance from water bodies was selected as unsuitable for quarry operation, and every 200m new classes were established (Table 10). The surface water bodies in the study area are dominant in Jarer and fafan streams. The Jarer stream passes across Jigjiga town, it drains from Chenaksen while the Fafan stream passes through Fafen town and drains to southern part of the study area. The areas within 150m distance along these streams were considered unsuitable for quarry operation and accounts 12% of the study area. The highly suitable class covers largest part of the area and accounts 60.3% (1286.3 km^2) of the study area.

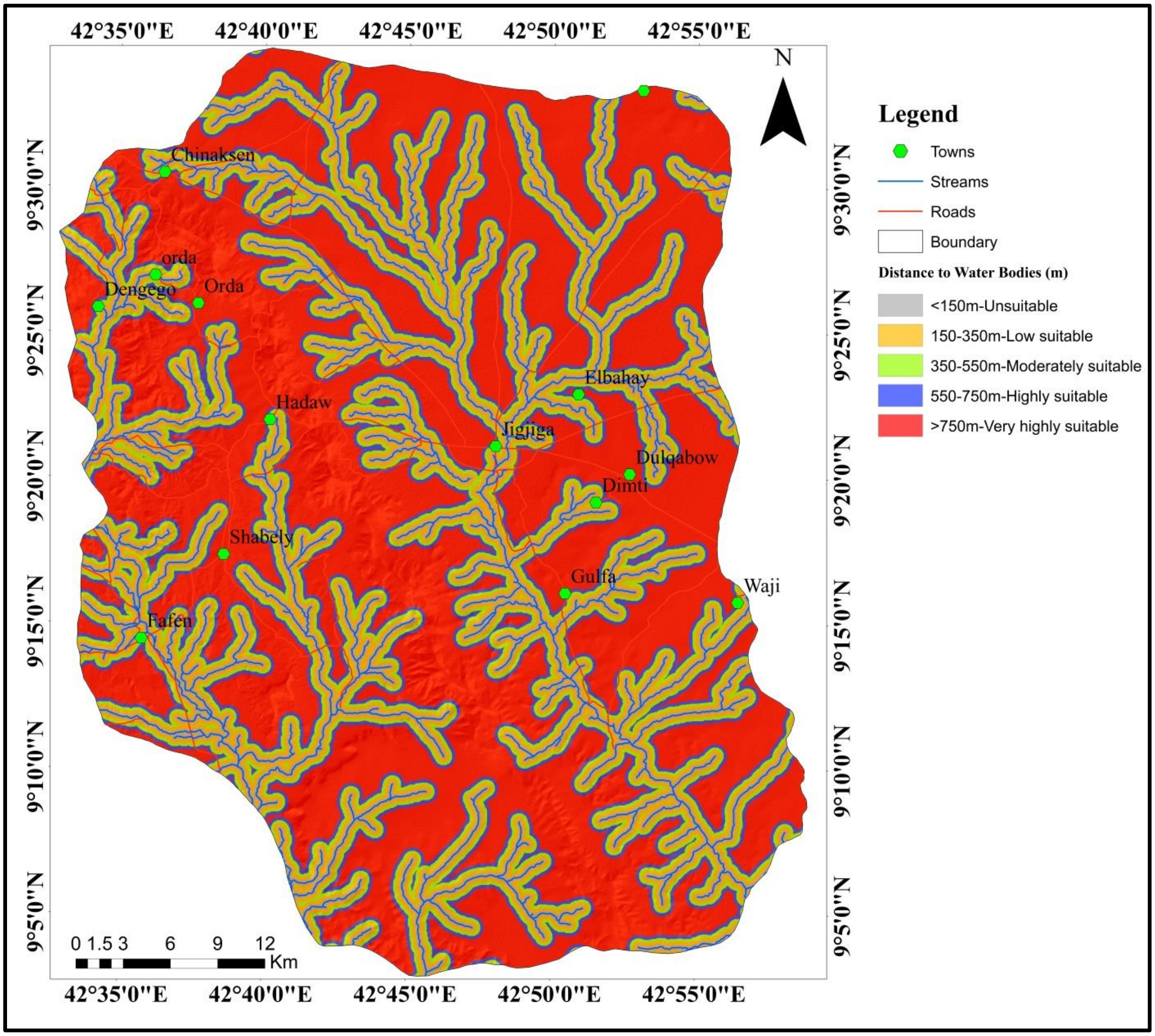

Figure 24 Reclassified distance to water bodies map

5.1.6 Distance to roads

Proximity of the quarry sites to roads is important for economic and transportation of the quarry product. According to Prentice (1990), the cost of transportation of aggregates doubles for every 10 miles increasing of road distance from source to the market. However roads close to quarry sites can easily be affected by dust, flying rock and vibration from quarry activity (Chabuk et al., 2017). Thus adequate buffer zone has to be established to protect the safety of roads. According to Gudissa et al. (2020), area within 500m distance to existing roads is more susceptible to damage from quarry activity, thus it is unsuitable for quarry operation.

Following this, areas within 500m distance to road were considered unsuitable for quarry site selection. On other hand areas more than 7500m distance from existing roads was selected as the least suitable sites due to cost of transportation. Furthermore areas between 2500m and 5000m is not close but not far and was selected the most suitable areas for quarry site. For the current study distance to existing roads were reclassified in to five sub classes based on their suitability for optimal quarry site selection. Unsuitable areas within 500m distance to existing roads cover area of 351 Km^2 (16.5%) of the study area while the most suitable areas (500-2500m) distance from existing roads covers area of 906.6 Km^2. (42.5%). The least suitable areas (>7500m), covers 10.2% of the study area.

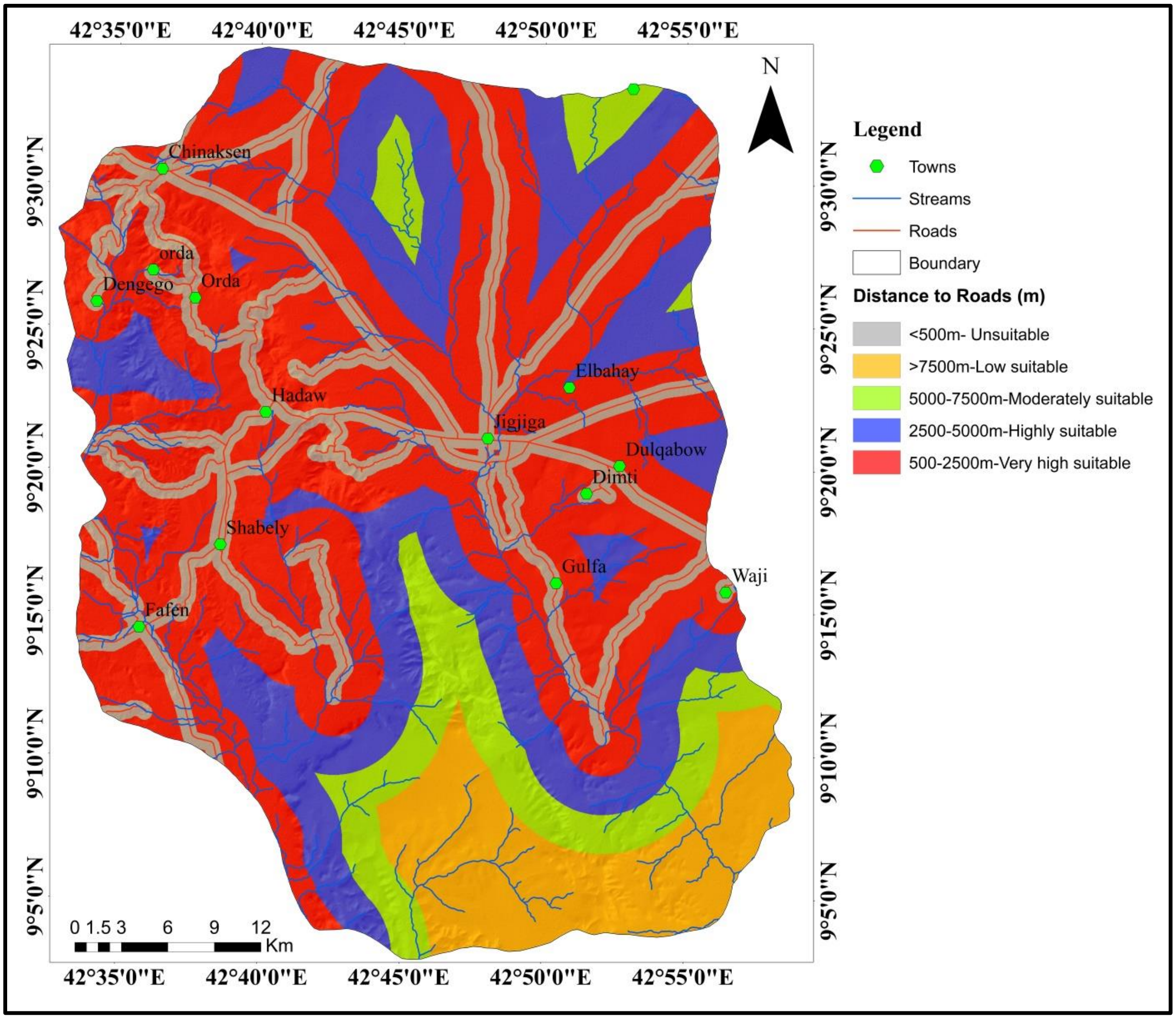

Figure 25 Reclassified Distance to roads map

5.1.7 Relative relief

Relative relief is important from slope instability point of view, flooding potential, ease of excavation, and accessibility (Alkaradaghi et al., 2019). Areas with relative relief of less than 5m may be accessible for quarry operation however it usually susceptible for flooding and possess difficulty in excavation and areas with 200m and more pose difficulty in accessibility and management (Gudissa et al., 2020). For the current study the relative relief was reclassified in five classes (Table 10). The classification was modified from Guddisa et al. (2020), in which the relative relief for current study was classified as <5m (very low, unsuitable), 5-50m (low, very highly suitable), 50-100m (moderate, highly suitable), 100-200m (High, moderately suitable), >200m (very high, less suitable) (Fig 26). Relative relief of <5m was selected unsuitable for quarry site and areas with 200m and more were considered as the least suitable areas for quarry site selection. Areas with relative relief of 5-50m were selected the most suitable sites for quarry operation and cover area of 1790 Km^2 (83%) of the study area while the unsuitable areas (<5m) covers small area of 0.2 Km^2 (0.009%). Highly suitable areas (50-100m) cover area of 249 Km^2 (11.7%) while the least suitable areas (>200m) accounts 0.009% which is very small area and moderately suitable sites (100-200m) cover 4.2% (91.6 Km^2). Based on the classification, the relative relief of the study area is highly suitable for quarry operation.

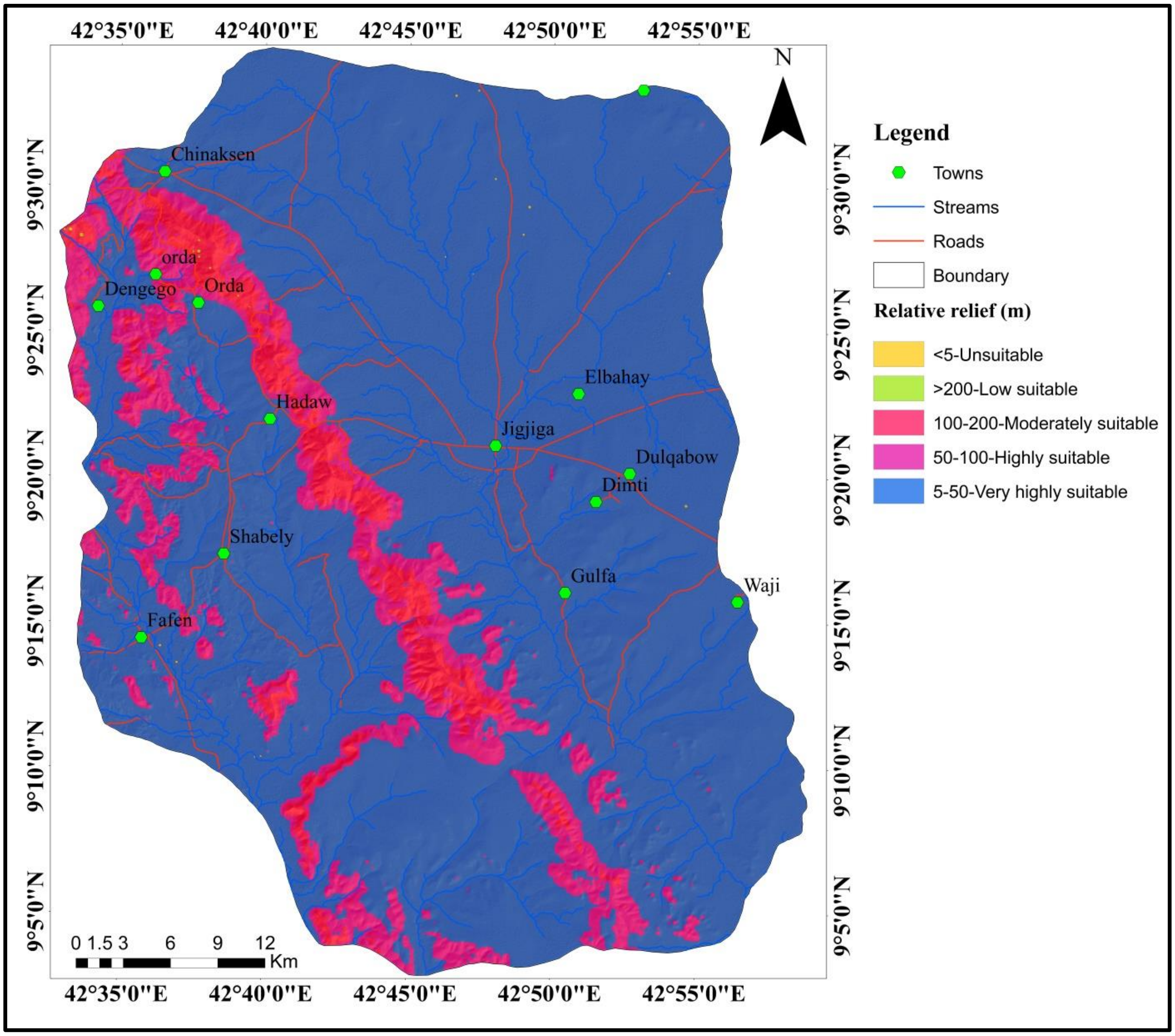

Figure 26 Reclassified relative relief map

5.1.8 Slope angle

Slope angle affects the stability of the quarry site. Generally, the stability of the slope decreases as the slope height increases (Raghuvanshi, 2019). In addition steep slopes may also pose problem for accessibility and difficulties in the excavation of rock (Gudissa et al., 2020). Hence generally steeper slopes are not suitable for quarry site and gentle slopes are the most suitable for quarry site. More ever very gentle slopes $<5^{o}$ also pose poor drainage, waterlogging and difficulty in excavation, thus a bit higher slope angle is suitable for the ease of quarry excavation (Gudissa et al., 2020). For current study the slope angle was reclassified in to five classes based on their suitability for quarry site (Fig.27). Very gentle slopes $<5^{o}$ was selected unsuitable for quarry site due to poor drainage, waterlogging and difficulty in excavation. In contrast slope angles of 5-15 ^{o} and 15-25^{o} were selected as very highly suitable and highly suitable respectively. Furthermore slope angles of 25-35 ^{o} was selected as moderately suitable were as steeper slopes >35 ^{o} were considered as the least suitable for optimal quarry site selection (Table 10). Very gentle slope(<5^{o}) covers most of study area about 1558.3 Km^{2} (73.3%) thus large part of the study area mainly in eastern part is unsuitable for quarry site due to poor drainage and water logging associated with very gentle slopes. In contrast very highly suitable slopes for quarry site selection (5-15 ^{o}) cover area of 448.3 Km^{2} (21%) of the study and it is found in the central and western part of the study area whereas steep slopes >35 ^{o} covers small area at the peak of Karamara mountain and represents 0.06 %. The slope angle of the area was generated from DEM with 30m resolution. Although slope angle is not the sole factor for slope instability but it triggers failure and affects the general stability of the quarry usually during torrential rainfalls.

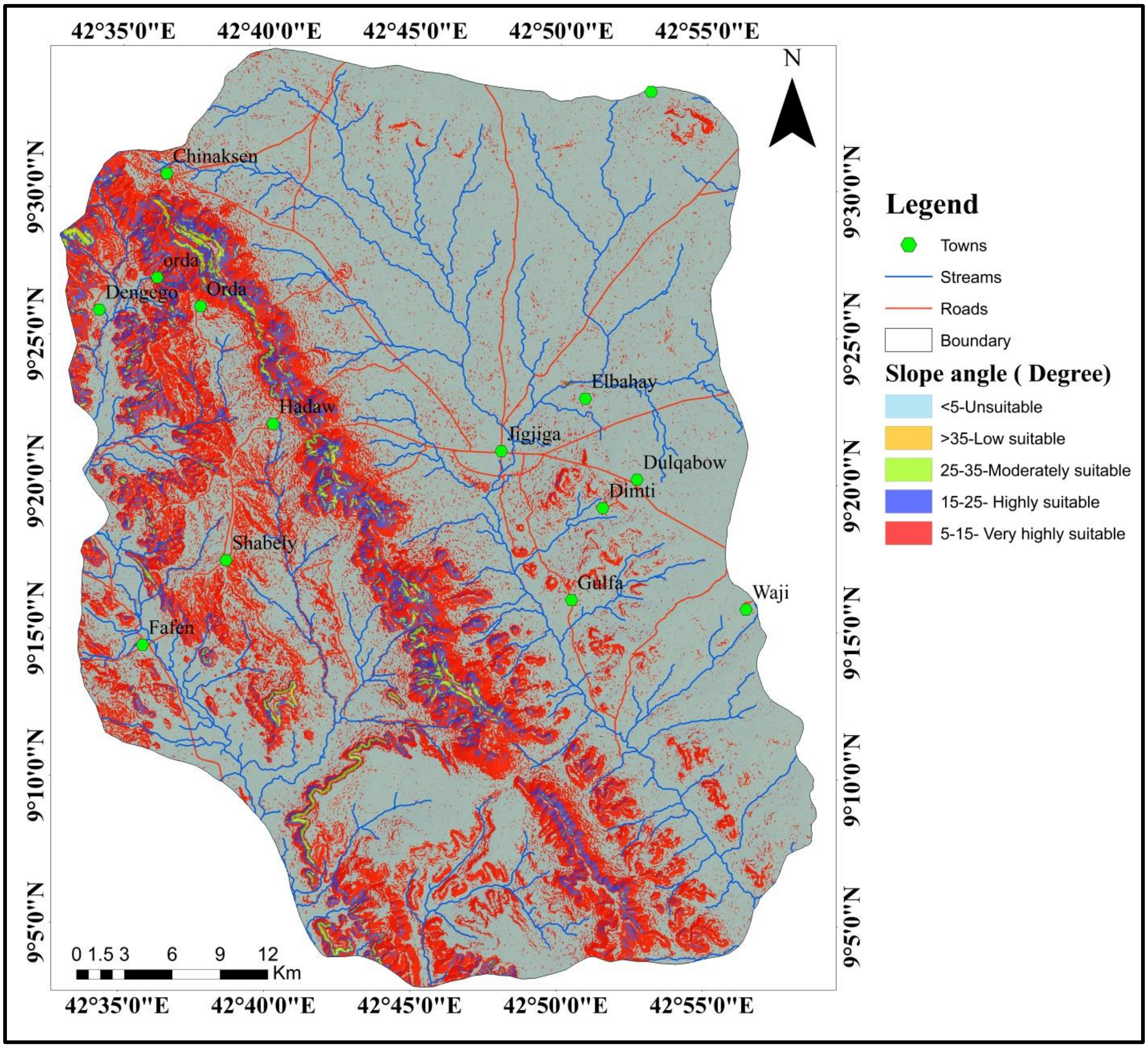

Figure 27 Reclassified relative relief map

5.2 Preliminary quarry site suitability map

Weighted overlay analysis was used to produce the final preliminary quarry site suitability map. The map was produced by first overlaying environmental and economic factors (Table 4) then the area that is eco-environmentally suitable and the area with suitable aggregates was extracted using math algebra product tool in Arc GIS to produce the final quarry suitability map. The weight of each factor was calculated (Table 9) using AHP- pairwise comparison matrix, depending on the relative importance of factors and consistency ratio of 0.025 was achieved, thus, the assigned weight for each factor is acceptable (Saaty, 2008). The preliminary quarry site suitability map depending on economic viability and environmental safety of the site was generated by overlaying seven factors. The relative importance of these factors was changed to percentage as weighted overlay analyses uses percentage, thus weight of 35%, 24%, and 16%, 10%, 7%, 5% and 3% was computed for land use land cover, distance to built up, overburden thickness, distance to water bodies, distance to roads, relative relief and slope angle respectively. Finally all the seven factors were overlaid using weighted overlay analysis and preliminary quarry site suitability map was generated for economic and environmental factors (Fig .28)

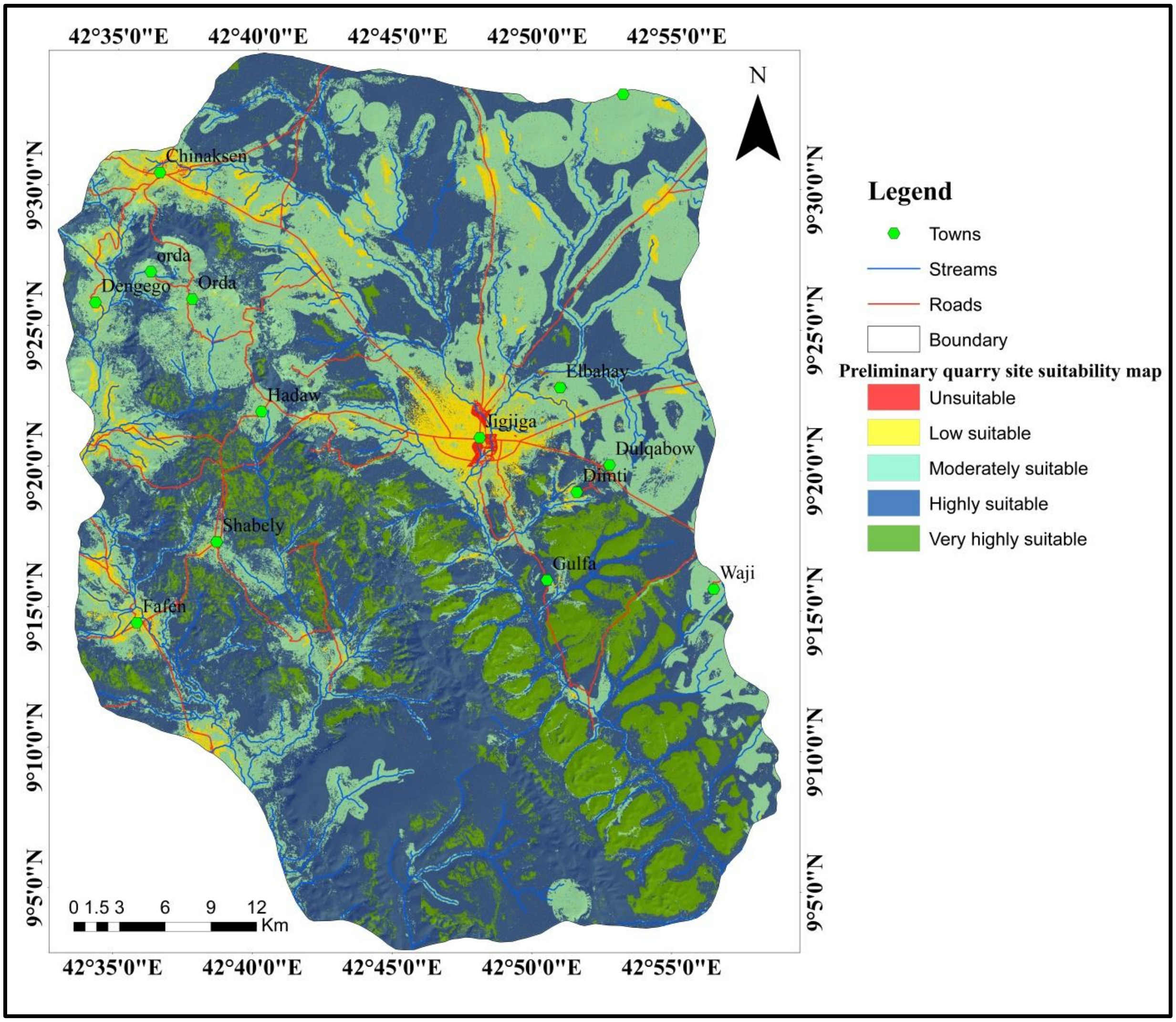

Figure 28 preliminary quarry site suitability map for economic and environmental factors

Based on this map, the highly suitable area account 50.2 %(1067.7 Km^2), of the study area, whereas very highly suitable areas cover area of 253.7 Km^2 (12%). Most of these areas are bare land and some part covered with sparse shrubs, far from buildup area and covered with thin overburden. The unsuitable areas cover very small area about 3.8 Km^2 (0.18%) due to small settlement and dense forest in the study area, also the unsuitable area of thick overburden material was very small. These factors highly affect the suitability of the sites as they have more impacts than other factors. The areas with low suitability are about 99.5 Km^2 (4.6%). These areas are mostly dense forest, agricultural land, close to built up area and are covered with thick overburden thickness. Moderately suitable areas cover area of 699 Km^2. (33 %), of the study area.

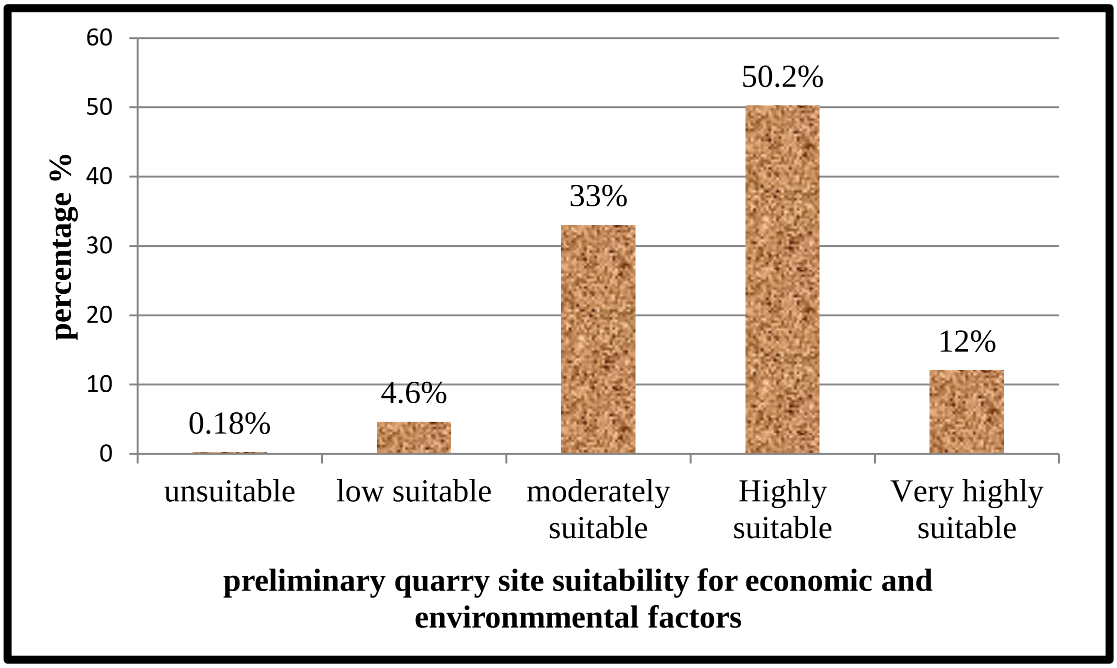

Figure 29 percentage of suitability for optimal quarry site of the study area

Lastly the final quarry site suitability map was produced using math algebra product of preliminary suitability map for economic and environmental factors and lithology. This is mainly done to extract the areas that are suitable in economic and environmental perspective as well as with good aggregate material. The classified lithology of the study which was reclassified into five classes (Fig.20) and preliminary suitability map for eco-environment factors (Fig.28) was multiplied using math algebra product in Arc GIS to extract overlapping area of the pixels suitable in preliminary quarry site suitability map and the suitable lithology for crushed stone aggregate. The final quarry site suitability map, which is generated by the product of the aforementioned raster maps, was reclassified into four classes which are unsuitable, low suitable, moderately suitable and highly suitable (Fig.30).

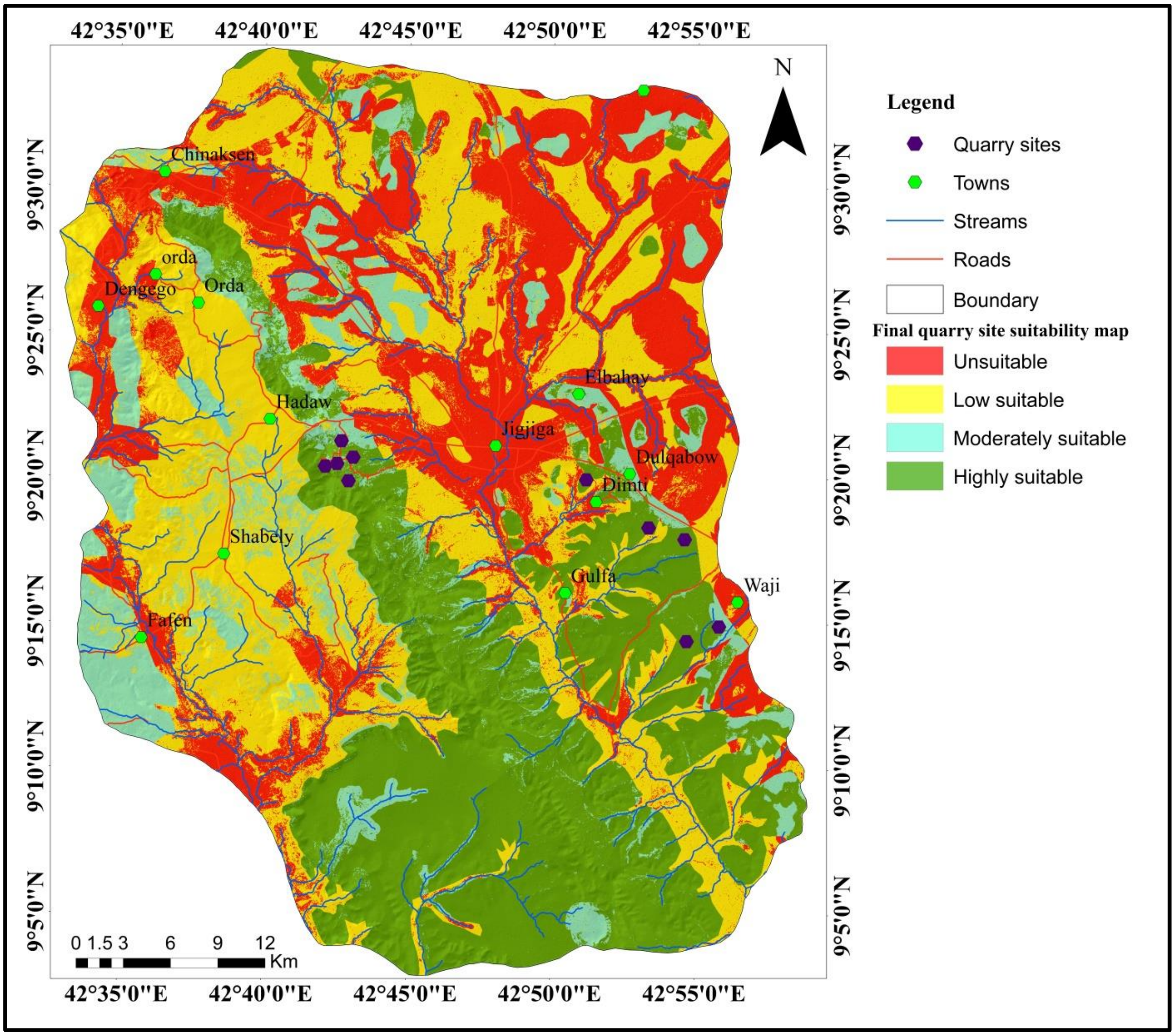

Figure 30 Final quarry site suitability map

The result of the map shows that 543.2 Km^2 (25.6%) of the study area is unsuitable for quarry site. This area dominantly occurs in northern and north eastern part of the study area and is covered with alluvium and eluvium deposit and also it is mostly settlement and agricultural land with low slope angle. The low suitable areas accounts 34.6% (735.6 Km^2) of the study area and cover large area at the western part of the study area, the area comprises sandstone, banded gneiss and amphibolite rocks and is covered with agricultural land, moderate to thick overburden deposits at Fafen, Dengago and Orda towns. The moderately suitable areas represent 11.6 %(246.7 Km^2), of the study area, and is sparsely distributed throughout the study area, these areas are mostly covered with granite and gabbro rocks. The highly suitable areas cover 28.2 % (598.4 Km^2), of the study area. These areas cover the central and southern part of the study area; the areas are covered by limestone and basalt, bare land and sparse shrubs with thin overburden thickness.

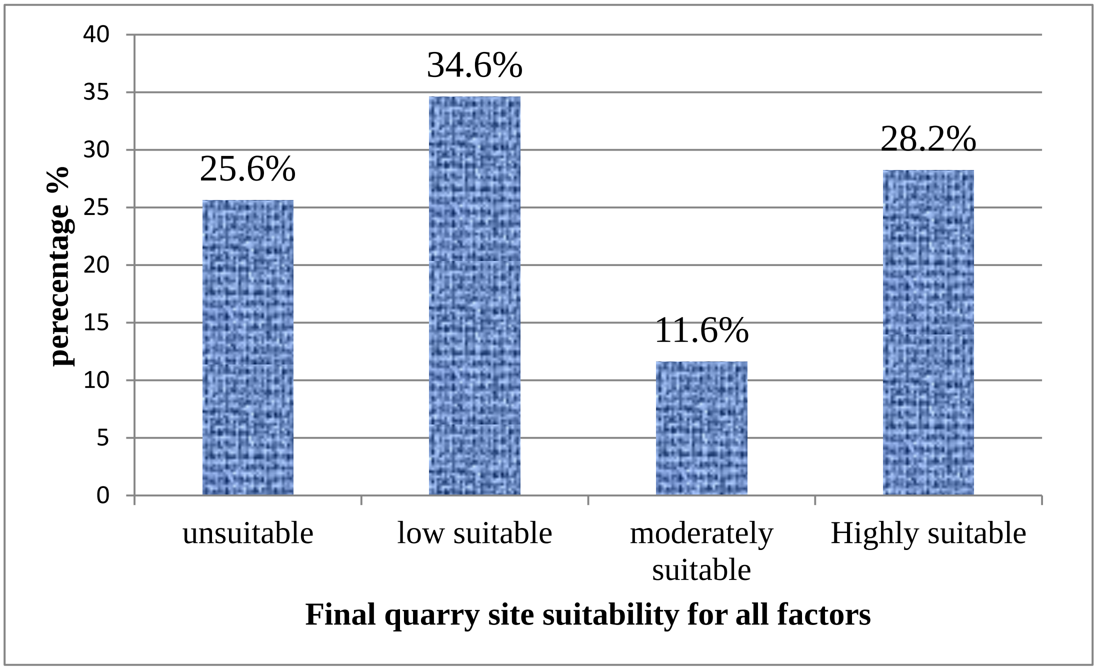

Figure 31 Percentage of quarry site suitability classes

5.3 Engineering geological characterization of crushed stone aggregates

Aggregates are the major materials required in construction of infrastructures such as air field pavement construction, roads, bridges and buildings (AL-Akhaly, 2018). Therefore the physical, mechanical and chemical property of the aggregate has great impact in concrete performance for construction use. Thus physico-mechanical tests have been conducted to assess the quality of the crushed stone aggregates extracted from highly suitable quarry sites in the study area. For current the study 10 quarry sites have been systematically selected from highly suitable quarry sites to characterize the engineering properties of the aggregates for construction use. The quarry sites selected are shown in figure 32 and are generally described in Table 11.

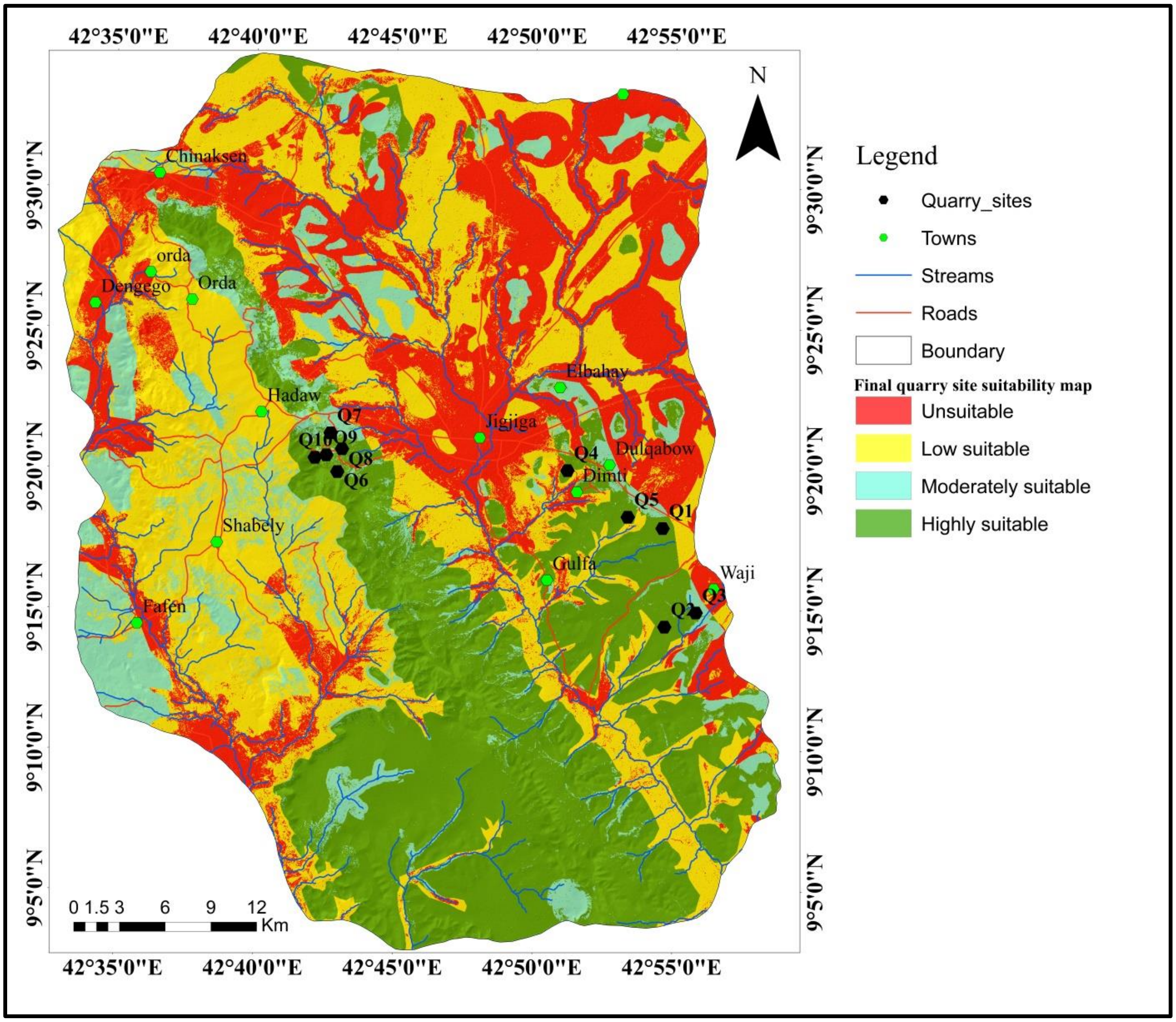

Figure 32 Locations of selected quarry sites for aggregate sampling

The quality of the aggregates extracted from selected quarry sites in the study area were investigated by conducting various physico- mechanical tests such as point load strength index, crushing value, impact value, Los Angeles abrasion value, water absorption, specific gravity, bulk density, aggregate shape test and sodium sulfate soundness test. The tests were conducted in accordance with ASTM and BS standards and the results are discussed below.

5.3.1 Bulk density

The bulk densities of the aggregates were determined in accordance with ASTM C 29/C 29M (2003). The bulk density of the aggregates ranges from 1908.5 Kg/m^3 (limestone) to 2365.6 Kg/m^3 (basalt) as shown in figure 33. Basaltic aggregates form quarry 6, 7, 8.9 and 10 showed higher bulk density relative to limestone aggregates from quarry 1,2,3,4, and 5. Aggregates with higher density have shown higher specific gravity and strength than aggregates with low densities. The uncompacted bulk density of normal aggregates ranges from 1200 Kg/m^3 to 1800 Kg/m^3 (BS 812-1, 1975)

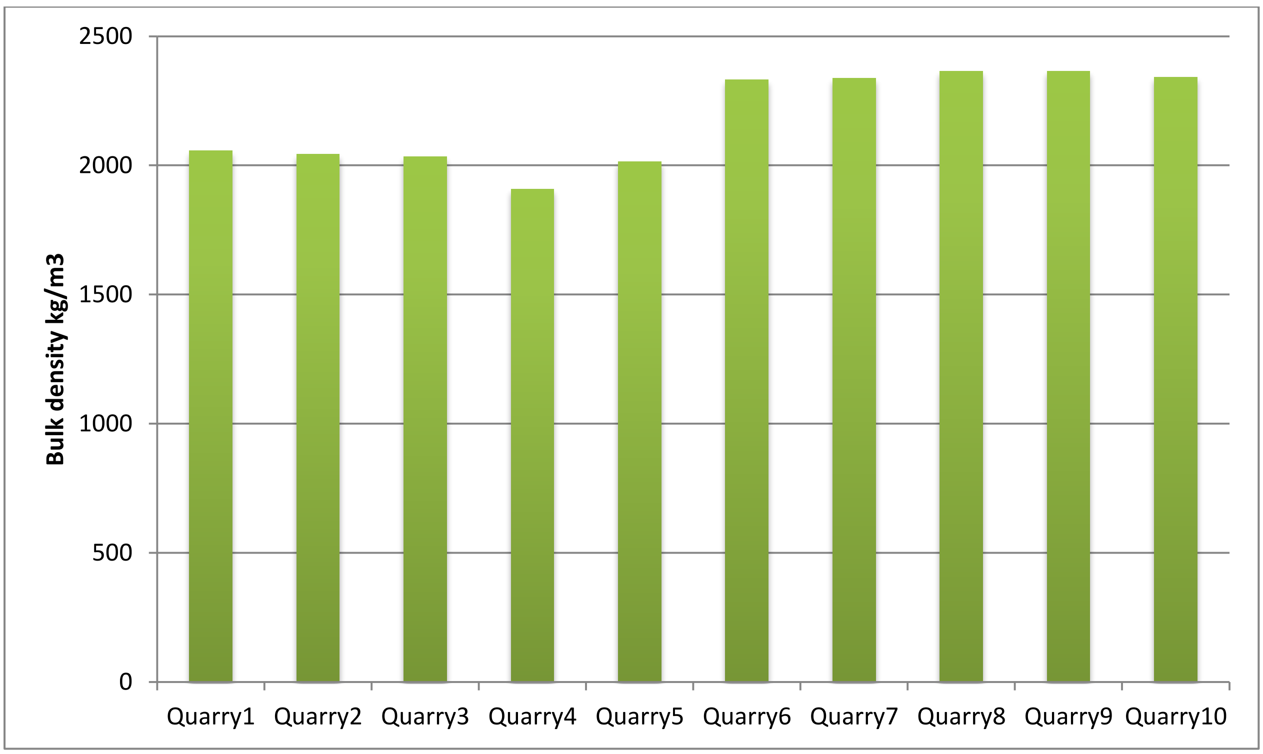

Figure 33 Bulk densities of the aggregates

5.3.2 Water absorption and Specific gravity

Water absorption of the aggregates was determined according to ASTM C 127 (2001). It is a measure of amount of water absorbed by aggregates. Water absorption is an indirect measure of the permeability of an aggregate, which, in turn affects the physical characteristics such as mechanical strength, shrinkage and to its general durability potential (Collis and Fox, 1985) also it is related to mechanical strength, soundness and durability (Smith and Collis, 1993;

Neville, 2000; Korkanc and Tugrul, 2004).The water absorption of the aggregates tested ranges from 0.5 to 5.4 % (Fig.34). Basaltic aggregates showed low water absorption than limestone aggregates. BS 812 (1990) and ASTM C 127 (2001) standards stated the maximum allowable value of water absorption for concrete aggregate is 2 and 2.5, respectively. Hence except aggregates form quarry 4 all other samples have shown good quality in term of water absorption (<2.5). Limestone aggregate samples from quarry 4 have shown water absorption of 5.4% which is beyond the standard speciation limit. Aggregate having higher water absorption are weak and porous in nature and are generally considered unsuitable for construction use (Schimdt and Graf, 1972).

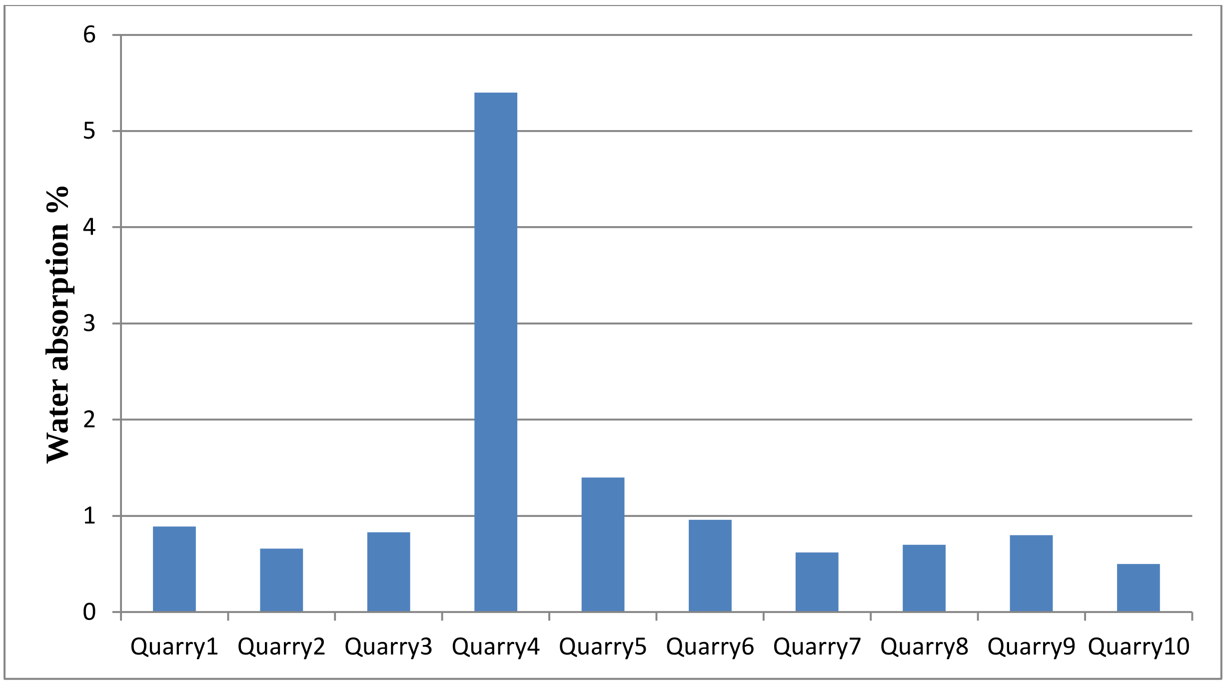

Figure 34 Water absorption

Specific gravity of the aggregates in saturated surface dry condition was determined in accordance with ASTM C 127 (2001). Specific gravity is important in calculating the mix design as it relates the weight of the aggregates to its volume (AL-Akhaly, 2018). There is generally a direct positive relationship between high specific gravity and high strength of aggregates (Kandhal and Lee, 1970; Neville, 2000). The specific gravity of the aggregates tested ranges from 2.46 to 2.9 as shown in figure 35. According to Blyth and De Freitas (2017), rocks with specific gravity of higher than 2.55 are suitable for construction. Hence except aggregates from quarry 4 all other samples have fulfilled the required specific gravity to be used for construction use.

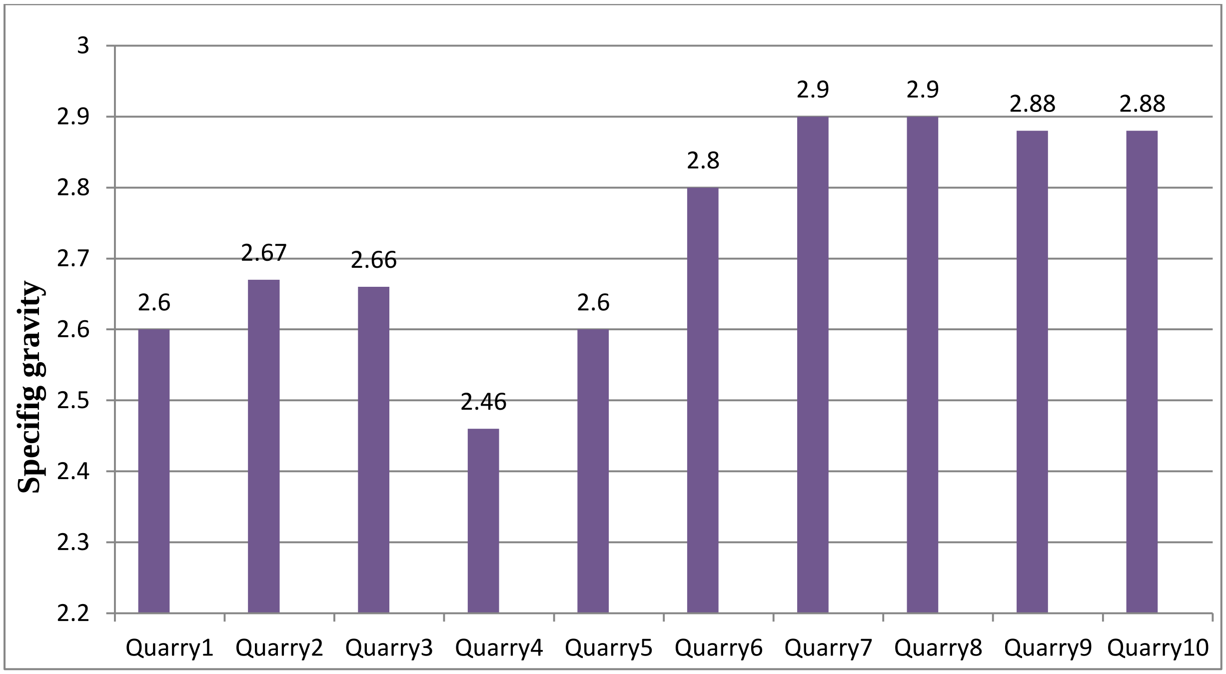

Figure 35 Specific gravity

5.3.3 Flakiness and Elongation index

Generally, flakiness and elongation indices are considered to be inherent characteristics of the rock itself, mostly determined by its mineralogy, texture, and structure, and partially determined by the crushing techniques used (Engidasew, 2014). Hard brittle rocks tend to produce more flake particles when crushed (Smith and Collis, 1993).The flakiness and elongation indices were determined in accordance with BS 812-105.1 (1989) and BS 812-105.2 (1990) respectively. The finding shows that the flakiness index ranges from 16.2 to 43.3% and the elongation index ranges from 6.4 to 21.7% (Figure.36). The basaltic aggregates have shown more elongation index than limestone aggregates. The maximum flakiness index (43%) was observed in fossiliferous limestone from quarry 5 in which the presence of thin elongated fossil shells made the aggregates to yield flaky particles when crushed, and the maximum elongation index (21.7%) was recorded in basaltic aggregates from quarry 10. According, to BS 812-105.1 (1989) and BS 812-105.2 (1990), the flakiness and elongation index of crushed stone aggregate should be a maximum of 25%. Accordingly all of the aggregates comply with the BS specification in terms of elongation index.

However, aggregates from quarry 5(43.2), 6 (34%) and 8 (29.3%) showed more flakiness index than required specification. However BS882 (1992) also states aggregates with maximum flakiness index of 40% can be utilized for construction purpose. Flaky and elongated aggregates are weak and tend to break easily during construction and post construction load, thus they produce weak concrete which is unsuitable to bear heavy weight.

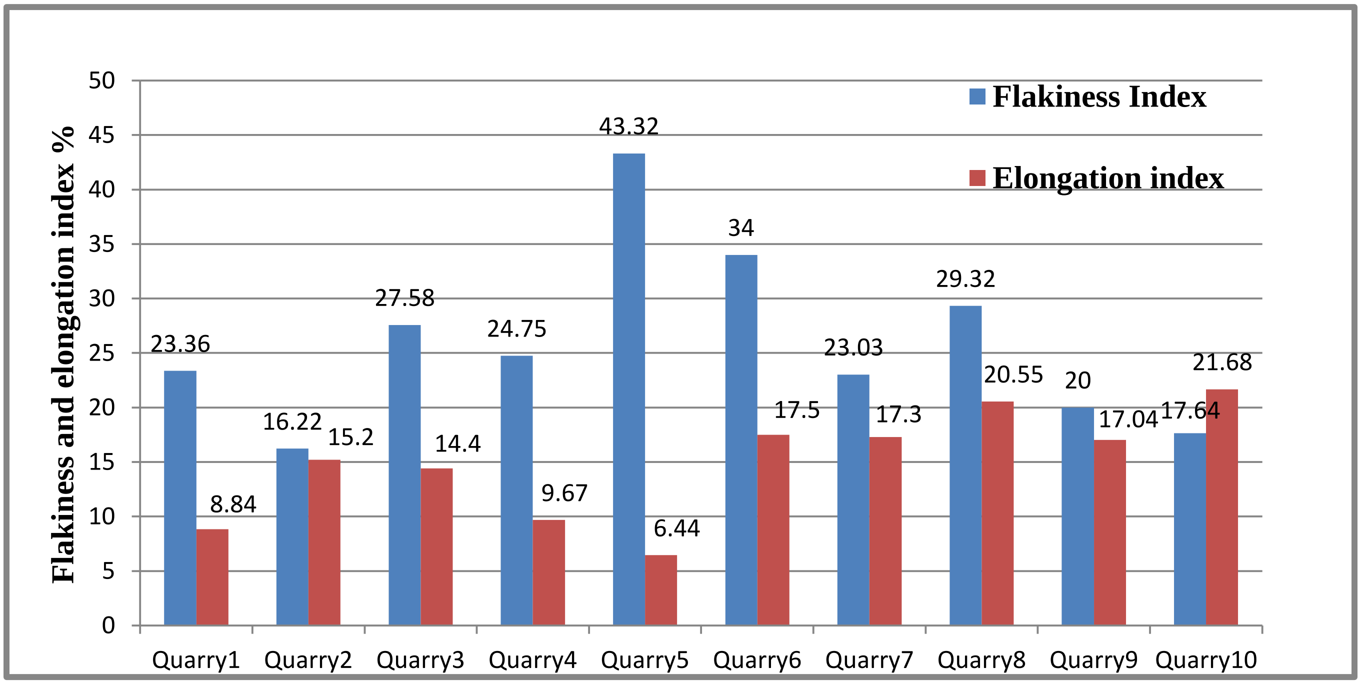

Figure 36 flakiness and elongation index

5.3.4 Point load strength

Point load strength of irregular rock samples was determined in accordance with ATM 5731(1995). The corrected point load strength (Is50) ranges from 1.5Mpa (weathered limestone) to 11.1Mpa (basalt) as shown in appendix A. The corrected point load strength was converted to unconfined compressive strength using equation 3.8 forwarded by Broch and Franklin (1972). The unconfined compressive strength of rock samples ranges from, 36.4Mpa (weathered limestone) to 267 Mpa (basalt) as shown in figure 37. The strength of concrete greatly depends on the unconfined compressive strength of the aggregates (Engidasew, 2014). According to Dearman (1981) and Bell (2007), the unconfined compressive strength of parent rock should be 35Mpa to be used for concrete production. In this case all the rocks tested satisfy the aforementioned specification.

However Lorentz et al (2003) as cited in Engidasew (2014), stated unconfined compressive strength of the parent rocks to be crushed and used for concrete should be greater than 60Mpa. The later specification makes the rocks from quarry 4 which has unconfined compressive strength of 36.4 Mpa unsuitable for concrete production. Generally the compressive strength of rocks is intrinsic characteristics but the degree of weathering and fractures greatly affects the strength, thus unweathered rocks samples should be used for crushed stone aggregate production.

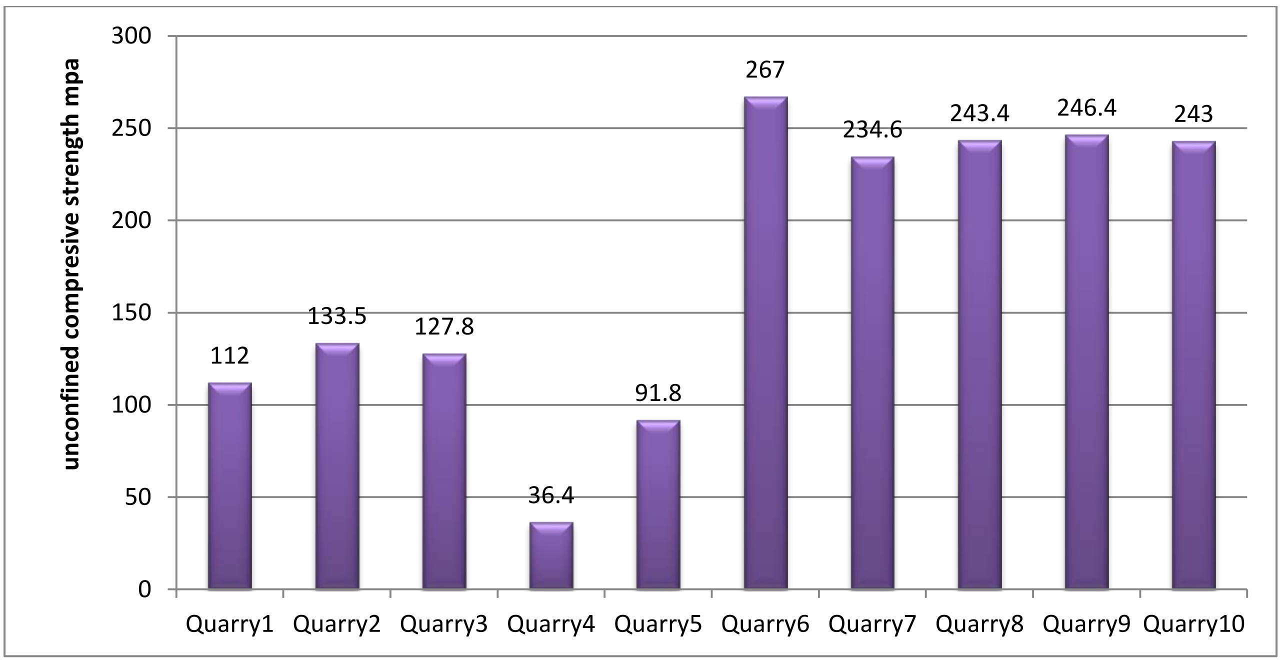

Figure 37 Unconfined compressive strength

5.3.5 Aggregate crushing value

Aggregate Crushing Value gives a relative measure of the resistance of an aggregate sample to crushing under gradually applied compressive load (Shetty, 1982). The crushing value was determined following BS 812-110:1990 in which aggregate passing sieve 14 and retaining on sieve 10mm was compresssed by gradually applied force until 400KN is attained in 10 minutes and the the percantge of sample passing sieve 2.36mm was recorded as aggregate crushing value. The lower the crushing indicate strong aggregate that withstand heavy loads.

The crushing value ranges from 13.3% to 45.7% as shown in fiugre 38. The limestone aggregates have shown more crushing value than basaltic aggregates.

According to BS 812-110 (1990); the maximum crushing value allowed is 25%. Except, limestone aggregates from quarry sites 1 and 4 all other aggregates meet the required specification for construction use.

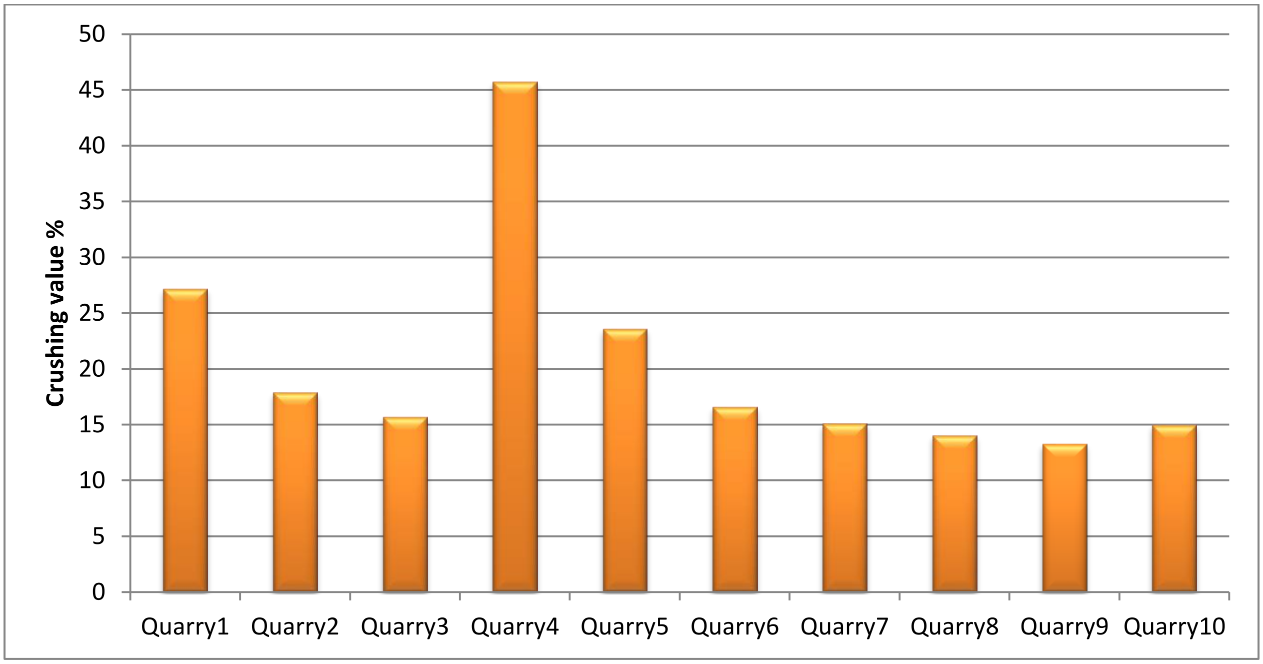

Figure 38 Aggregate crushing value

5.3.6 Aggregate impact value

Aggregate impact value is a relative measure of toughness of the aggregate to resist impact against moving loads. Aggregate impact value was determined in accordance with BS 812-112 (1990). Lower impact value indicates stronger hard rocks that can resist heavy impact from moving loads. For the current study, the impact value ranges from 7.3% to 19% as shown in figure 39. Basaltic aggregates have shown lower impact value relative to limestone aggregates. According to BS 812-112 (1990) and (ASTM C 131-96 as cited in Al-Alkhaly, 2018) the maximum allowed impact value for wearing course in pavement is 25%. Accordingly all the aggregates tested fall within the range specified by BS 812-112:1990 and ASTM C 131-96. The impact value is affected by parent rock characteristics such as mineral composition, grain size and fabric (Ramsay et al., 1974).

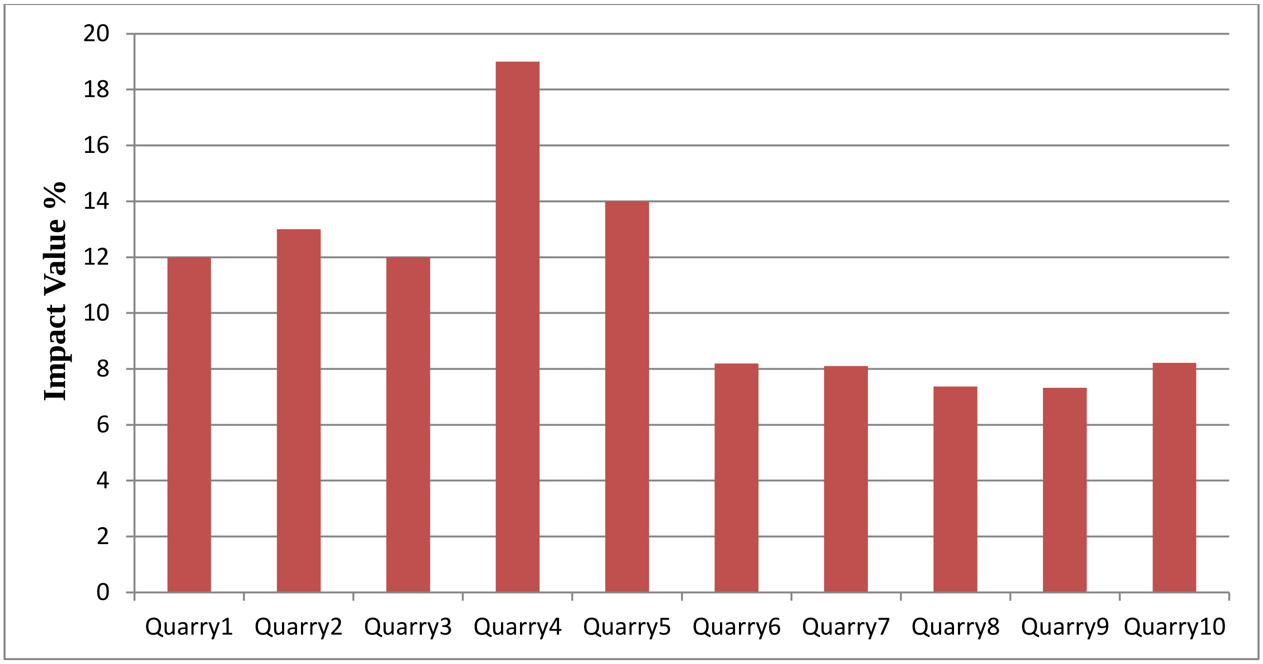

Figure 39 Aggregate impact value

5.3.7 Aggregate abrasion value

Generally aggregates must be durable or resistant wear and deterioration (Smith and Collis, 1993). To assess the resistance of the aggregates against wearing Los Angeles abrasion test was conducted using the Los Angeles abrasion machine. Weak aggregates tend to show significant volume change, resulting in the deterioration of concrete when subjected to different environment conditions (Waqa, 2004). Aggregates should be strong, hard, dense and free from soft material to resist abrasion. For the current study, the abrasion test was conducted following ASTM C 131 (2003) test mehod . The abrsion value ranges from 12.4% (basalt) to 39% (limestone) as shown in figure 40. According to specification provided by ASTM C 33 (2003), the maximum allowed abrasion value for concrete and pavement wearing course should be 50%. Accordingly, all the aggregates satisfy the specification mentioned.

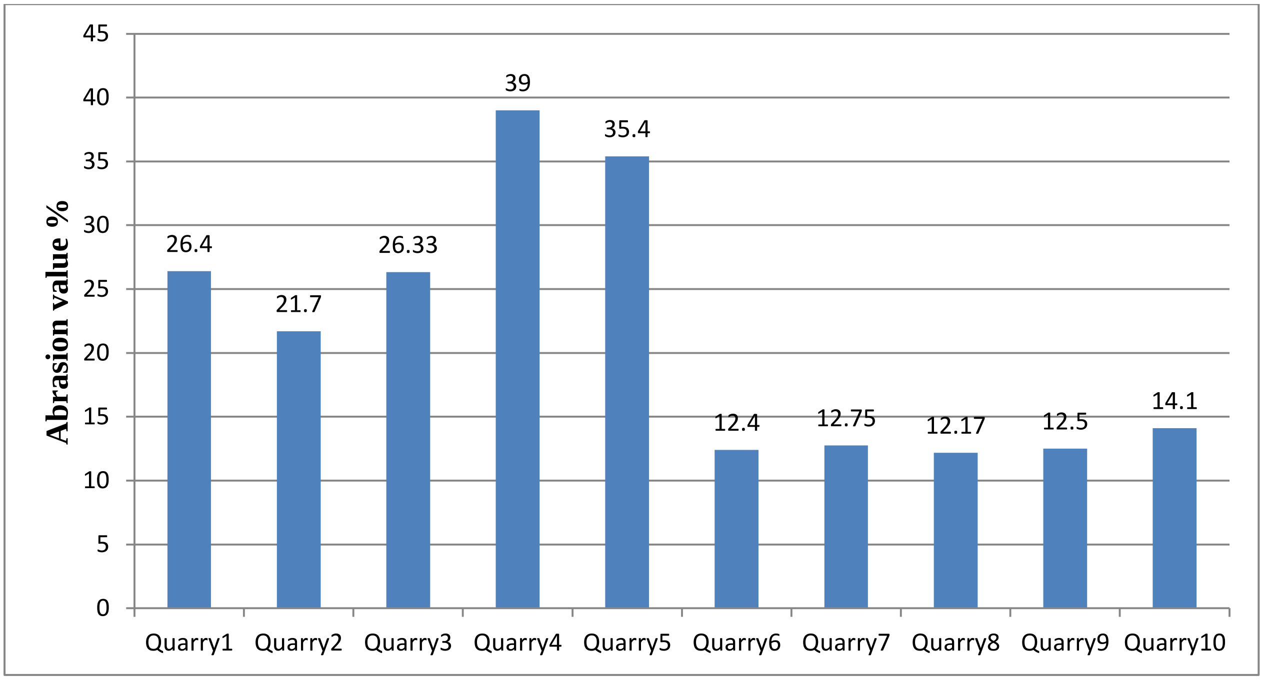

Figure 40 Aggregate abrasion value

5.3.8 Sodium sulphate soundness test

soundness is the capacity of aggregates to withstand severe volume change caused by changes in the physical environment, such as freeze-thaw cycles, thermal changes at temperatures above freezing, and so on (Smith and Collis, 1993). Soundness of the aggregates was assessed using sodium sulphate solution following procedures provided by ASTM C 88 (1999). The sodium sulphate soundness test evaluates the resistance of aggregate particles to degradation and disintegration that occurs due to crystallization of salts within pores and interstices of particles (Wu et al., 1988). The sodium sulphate soundness value ranges from 3.55 (basalt) to 16.9 % (limestone) as shown in figure 41. Coarse grained porous weak rocks tend to have break easily during freezing and thawing. Sodium sulphate soundness observed in limestone aggregates is higher than basaltic aggregates. According to ASTM C 33 (2003), the maximum sodium sulphate soundness value of aggregates used for conctrete and pavement should be 12%. In this case except limestone aggregates from quarry sites 4 and 5 all other aggregates fall within in the required specification.

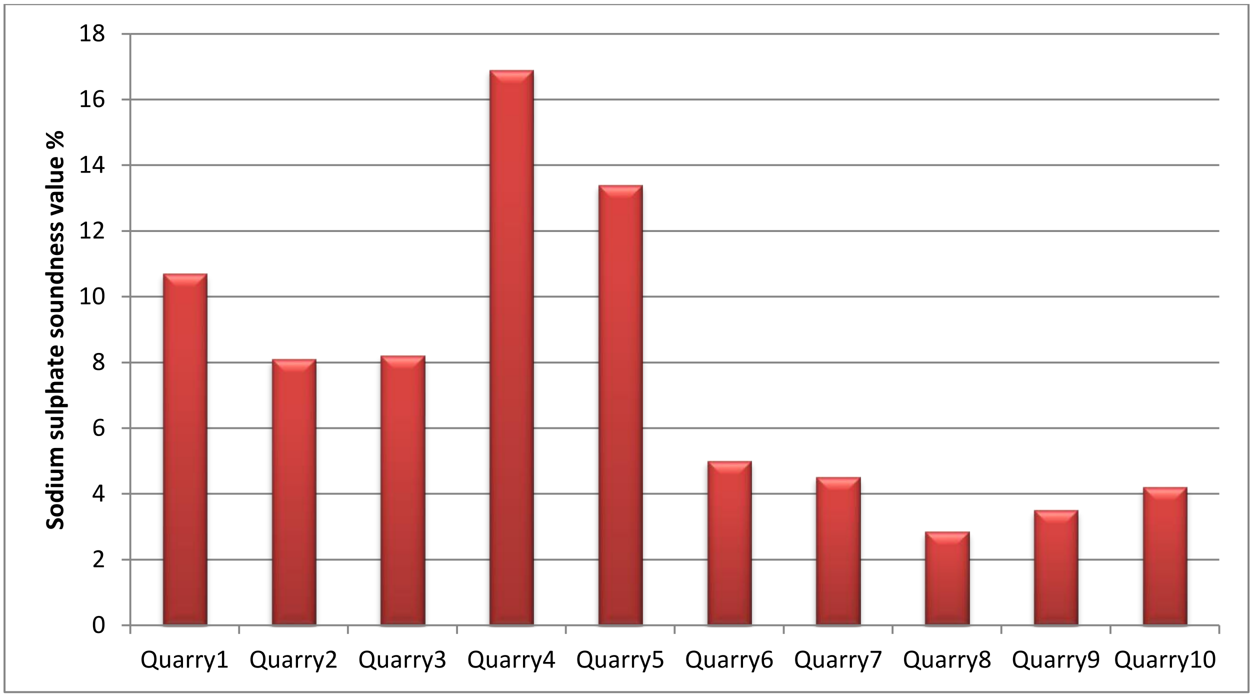

Figure 41 Sodium sulphate soundness test

5.4 Petrographic analysis

Petrographic study shows the textural and mineralogical composition of a rock based on thin section study (Hussain et al., 2022). It is a microscopic examination that evaluate the aggregate material (French, 1991) and is used to examine the presence of deleterious substance that cause Alkali-Aggregate-Reaction (AAR) risk in aggregates which causes major damage in concrete (Engidasew, 2014) The petrographic thin section of 10 samples from selected quarry sites was prepared and analyzed for determining the mineralogical composition. The mineral composition and texture observed in limestone sample are presented in Table 14

Table 14 mineral composition and texture of limestone aggregates

ID	Rock type	texture	Grain size	Mineral composition %			
				calcite	Clay	Opaque (Fe-oxide)	Fossil
Q1	Argillaceous Limestone	Mud supported	Fine grained	50	48	2	-
Q2	Argillaceous Limestone	Mud supported	Fine grained	57	40	2	1
Q3	Argillaceous Limestone	Mud supported	Fine grained	49	47	4	-
Q4	Argillaceous Limestone	Mud supported	Fine grained	50	47	3	1
Q5	Fossiliferous limestone	Mud supported	Coarse grained	65	20	3	12

The limestone aggregates showed fine grained mud supported texture with varying of composition calcite, clay, fossil and opaque minerals (Fe-oxide).

The basaltic aggregates are composed of plagioclase, olivine, volcanic glass and opaque minerals. The mineral composition and texture of basaltic aggregates is shown in Table 15

Table 15 mineral composition and texture of basaltic aggregates

ID	Rock type	texture	Grain size	Mineral composition %				
				Plagioclase	pyroxene	Olivine	Volcanic glass	Opaque (Fe-oxide
Q6	Basalt	Inter granular	Fine grained	49	40	2	4	5
Q7	Basalt	Porphyritic	Fine grained	46	41	3	6	4
Q8	Basalt	Porphyritic	Fine grained	47	38	6	7	2
Q9	Basalt	Porphyritic	Fine grained	49	42	4	3	2
Q10	Basalt	Porphyritic	Fine grained	48	43	2	3	4

The petrographic thin section analyses under petrographic microscope of limestone sample from quarry 1 shows calcite gains cemented by clay. It also shows presence opaque minerals. The hand specimen has grey color and fine grained.

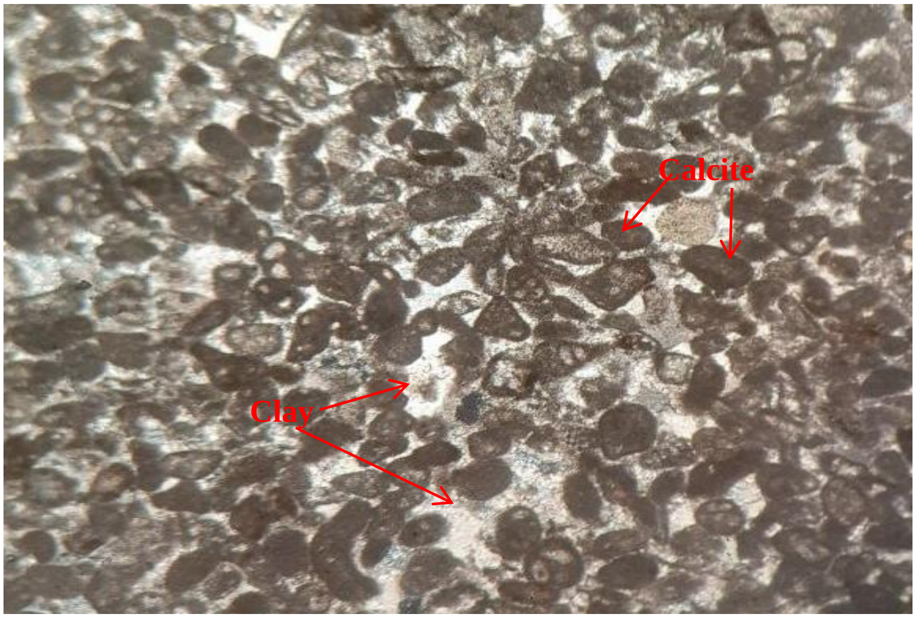

Figure 42 Microphotography of sample from quarry 1

The petrographic thin section analyses of limestone sample from quarry 2 shows mud supported texture and composition of calcite, clay, opaque minerals and fossils as shown in microphotography in figure 43. The hand specimen has grey color and fine grained texture.

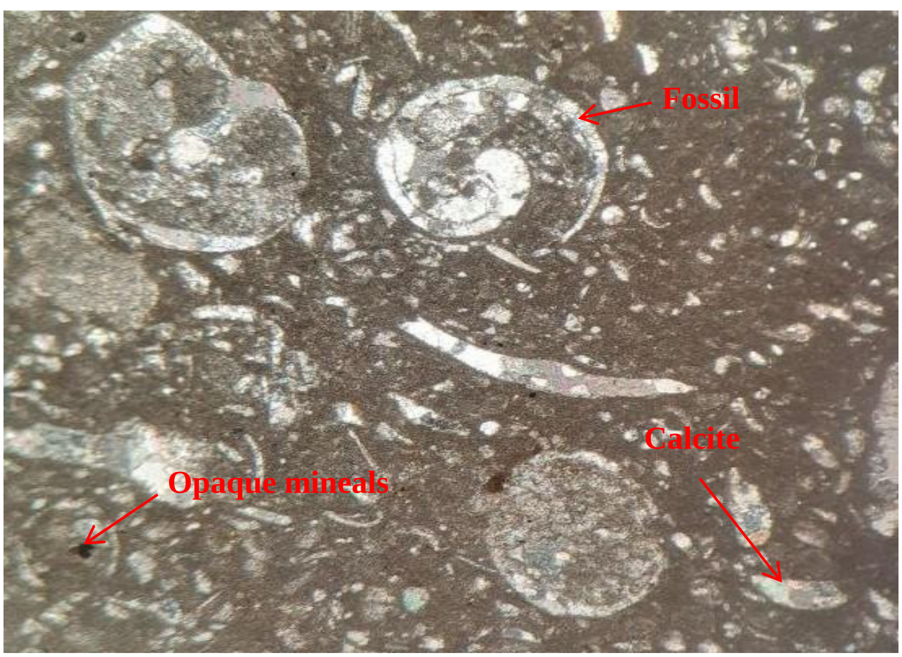

Figure 43 microphotography of limestone sample from quarry 2

The hand specimens of aggregates from quarry 3 shows whitish grey color and are fine grained. The thin section of this rock shows calcite, clay and opaque minerals as shown in figure 44.

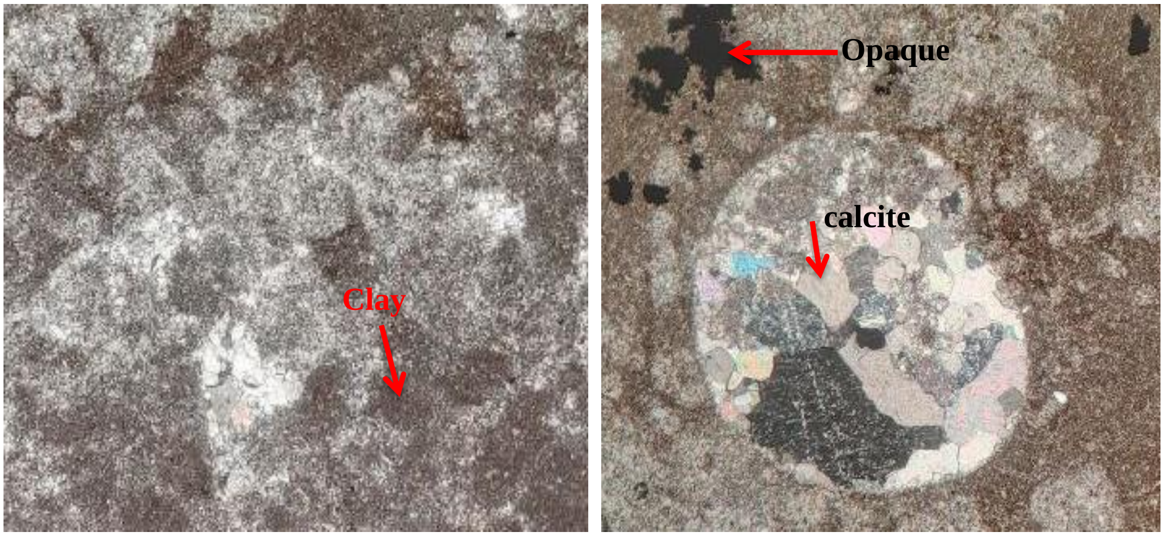

Figure 44 microphotography of rock from quarry 3

The hand specimen of rock from quarry 4 shows fine grained and whitish grey color. The petrographic thin section shows fine grained texture with mineral composition of calcite, clay and opaque mineral. The hand specimen of rock from quarry 5 has grey color and fine grained, containing fossils. The thin section analysis reveals presence of calcite, Clay fossils and opaque minerals.

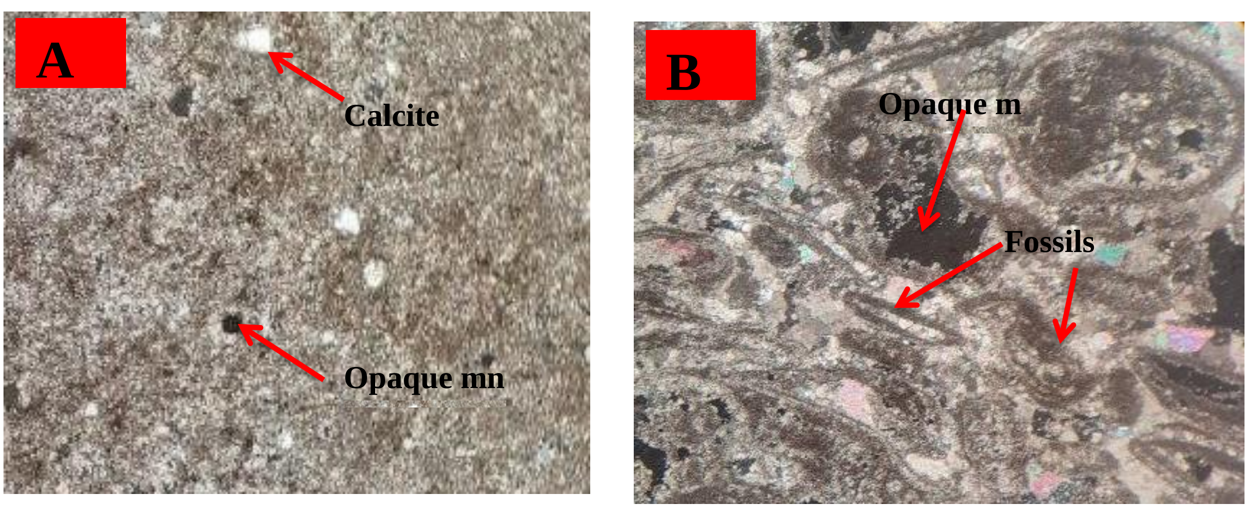

Figure 45 Microphotography of rocks from quarry 4(A) and Q5 (B)

The hand specimens of quarry 6 and 7 rocks have dark grey color and fine grained texture. The petrographic thin section of rock sample from quarry 6 showed mineral composition of plagioclase, pyroxene and mirror amount of olivine, volcanic glass and opaque minerals. The sample shows inter granular texture in petrographic microscope. Similarly the sample from quarry 7 is composed of plagioclase, pyroxene, olivine and volcanic glass, the rock is porphyritic in texture.

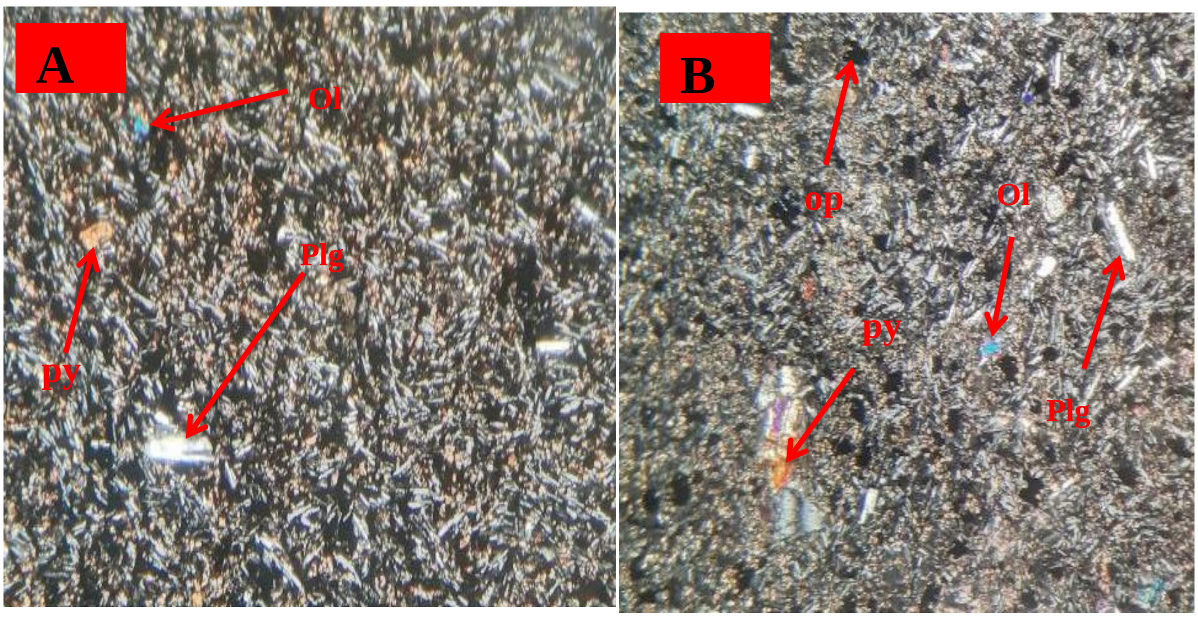

Figure 46 microphotography of rock samples from quarry 6(A) and Q7 (B)

The hand specimen of rock samples from quarry 8 and 9 are dark grey in color and fine grained in texture. The petrographic thin section analysis of both samples show mineral composition of plagioclase, pyroxene, olivine, volcanic glass and opaque minerals. The rocks show porphyritic texture. Plagioclase and pyroxene accounts more than 70% of the rocks. The samples contain minor amount of olivine, volcanic glass and opaque minerals.

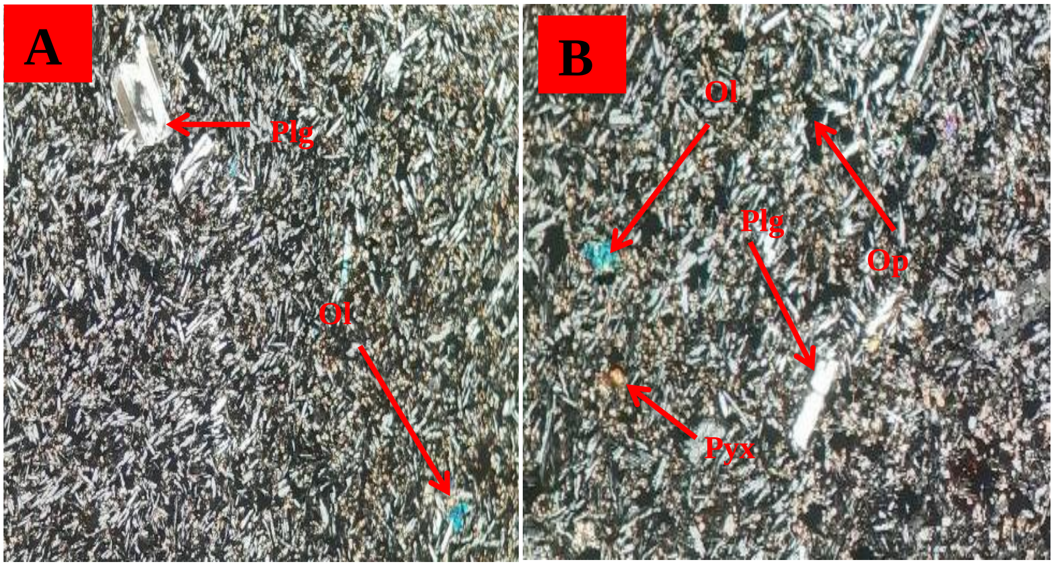

Figure 47 Microphotography of rocks from Q8 (A) and Q9 (B)

The hand specimen of rocks from quarry 10 has dark grey color and fine gained texture. The petrographic thin section shows mineral composition of plagioclase, pyroxene, Olivine, volcanic glass and opaque minerals. The rock has porphyritic texture.

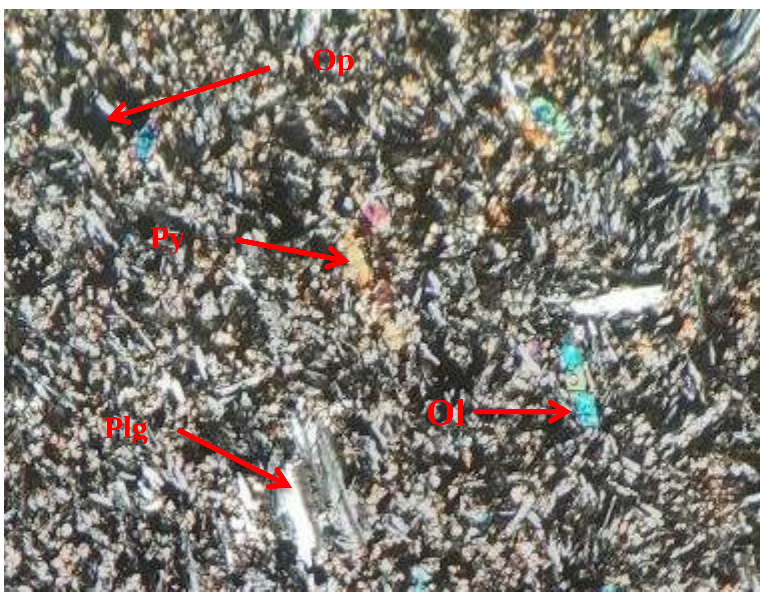

Figure 48 Microphotography of quarry 10 rock

The mineralogical composition of the rocks identified by petrographic thin section analyses allows qualitative examination of deleterious mineral that causes alkali-silica reactivity. Alkali-silica reaction (ASR) is a chemical reaction between the reactive silica contained in aggregates and the alkalis in the cement paste (Farny and Kosmatka, 1997). Certain minerals are highly reactive with alkalis in the cement and cause alkali-silica reactivity. These include forms of silica such as opal, chalcedony tridymite, and cristobalite; cryptocrystalline and microcrystalline, strained, or highly fractured quartz; and intermediate to acid (silica-rich) volcanic glass which is likely to occur in rhyolite, andesite, or dacite (ASTM C 33, 2003). Severe alkali-silica reactivity produces cracking at surface which damages the structure. These troubles can be avoided if a preliminary petrological examination is made of the aggregate (Bell, 2007). Determination of the presence and quantities of these materials by petrographic examination is helpful in evaluating potential alkali reactivity (ASTM C 33, 2003). According to Bell (2007), aggregates that contain over 0.25% opal, over 5% chalcedony, or over 3% glass or cryptocrystalline acidic to intermediate volcanic rock, by weight, will be sufficient to produce an alkali reaction in concrete, unless low-alkali cement is used.

For current study no opal, chalcedony and chert was observed in limestone aggregates, hence the limestone aggregates does not contain reactive form of silica and has no potential to cause severe alkali-silica reactivity. The basaltic aggregates from quarry 6, 7 and 8 contain more than 3% of volcanic glass, which is sufficiently enough to generate alkali-silica reactivity unless low alkali cement is used as specified by Bell (2007). For quantitative analyses of alkali-silica reactivity of the aggregates alkali-silica reactivity test has to be conducted to identify the reactivity of the aggregates.

5.5 Correlation between physico-mechanical and pertographical properties of aggregates

The correlation between physical and mechanical properties as well as mineral composition of aggregates has been studied by many researchers (Brattli, 1992; Hartley, 1974; Smith and Collis, 2001; Makani and Vidal, 2013). The mineralogical composition, texture, weathering and alteration degree of the aggregates rocks greatly affect the physico- mechanical properties of aggregates and their quality for industrial application (Rigopoulos et al., 2012) as well as the long term performance in constructions (Petrounias et al., 2018). Based on the laboratory test result of physico-mechanical properties and the mineralogical composition of the aggregates determined by thin section analyses, an attempt has been made in present study to correlate the physico-mechanical and mineralogical composition of the aggregates.

Water absorption is inversely correlated with plagioclase, pyroxene, olivine, volcanic glass and opaque minerals (R= -040, -0403;-0341; -036; -0031) respectively. The basaltic aggregates dominated by these minerals have shown less water absorption than limestone aggregates which are dominated by calcite, clay and fossils. The water absorption has moderately positive relationship with calcite, clay and fossils (R= 0361; 0429; 010) respectively (Table 16). The specific gravity and bulk density has strong positive relationship with Plagioclase, pyroxene, olivine and volcanic glass and has low relationship with presentence of opaque minerals (Table 16). The aggregates dominated by calcite, clay and fossil have been negatively correlated with specific gravity and bulk density. The flakiness index is inversely correlated with plagioclase, pyroxene, olivine and volcanic glass and is directly correlated with calcite, opaque minerals and fossils. The elongation has direct relationship with plagioclase, pyroxene, olivine and opaque minerals and inverse relation with calcite, clay and fossil.

Table 16 Correlation between physical properties and mineralogical composition of aggregates

		Plagioclase	Pyroxene	Olivine	Volcanic Glass	Calcite	Clay	Fossil	Opaque(Fe-oxide)
Water absorption	Pearson Correlation	-.400	-.403	-.341	-.362	.361	.429	.101	-.031
	Sig. (2-tailed)	.252	.248	.335	.304	.306	.216	.782	.932
	N	10	10	10	10	10	10	10	10
Specific gravity	Pearson Correlation	.913**	.917**	.832**	.854**	-.895**	-.875**	-.369	.164
	Sig. (2-tailed)	.000	.000	.003	.002	.000	.001	.293	.651
	N	10	10	10	10	10	10	10	10
Bulk density	Pearson Correlation	.974**	.972**	.852**	.875**	-.957**	-.918**	-.389	.204
	Sig. (2-tailed)	.000	.000	.002	.001	.000	.000	.266	.571
	N	10	10	10	10	10	10	10	10
Flakiness index	Pearson Correlation	-.144	-.172	-.080	-.019	.223	-.084	.721*	.266
	Sig. (2-tailed)	.692	.635	.826	.957	.536	.817	.019	.458
	N	10	10	10	10	10	10	10	10
Elongation index	Pearson Correlation	.820**	.821**	.718*	.744*	-.843**	-.684*	-.620	.237
	Sig. (2-tailed)	.004	.004	.019	.014	.002	.029	.056	.510
	N	10	10	10	10	10	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

The unconfined compressive strength is positively correlated with plagioclase, pyroxene, olivine, volcanic glass and opaque minerals while the crushing, abrasion, impact and sodium sulphate soundness values are negatively correlated with these minerals. The crushing, abrasion, impact and soundness value are positively correlated with calcite, clay and fossil. The basaltic aggregates dominated by plagioclase, pyroxene, olivine and volcanic glass have shown higher unconfined compressive strength than limestone aggregates dominated by calcite, clay and fossil. The limestone aggregates dominated by calcite and cemented by clay have observed with higher crushing, abrasion, impact and soundness value (Table 17).

Table 17 Correlation of mechanical and mineralogical composition of aggregates

		Plagioclase	Pyroxene	Olivine	Volcanic Glass	Opaque(Fe-oxide)	Calcite	Clay	Fossil
Unconfined compressive strength	Pearson Correlation	.945**	.940**	.783**	.828**	.284	-.927**	-.880**	-.419
	Sig. (2-tailed)	.000	.000	.007	.003	.427	.000	.001	.228
	N	10	10	10	10	10	10	10	10
Impact value	Pearson Correlation	-.855**	-.852**	-.763*	-.773**	-.157	.839**	.802**	.368
	Sig. (2-tailed)	.002	.002	.010	.009	.665	.002	.005	.295
	N	10	10	10	10	10	10	10	10
Crushing value	Pearson Correlation	-.594	-.594	-.535	-.533	-.141	.555	.609	.182
	Sig. (2-tailed)	.070	.070	.111	.113	.697	.096	.062	.615
	N	10	10	10	10	10	10	10	10
Abrasion value	Pearson Correlation	-.881**	-.877**	-.764*	-.800**	-.160	.882**	.774**	.548
	Sig. (2-tailed)	.001	.001	.010	.005	.659	.001	.009	.101
	N	10	10	10	10	10	10	10	10
Soundness value	Pearson Correlation	-.837**	-.834**	-.770**	-.769**	-.129	.835**	.750*	.491
	Sig. (2-tailed)	.003	.003	.009	.009	.722	.003	.013	.150
	N	10	10	10	10	10	10	10	10

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

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

Unconfined compressive strength is inversely correlated with water absorption (Figure.49). It is also positively correlated with specific gravity and bulk density. Crushing, abrasion, impact and soundness value are positively correlated with water absorption and flakiness index. Aggregates with higher water absorption and flakiness index have also shown higher crushing, abrasion, and impact and soundness value. Specific gravity and bulk density are negatively correlated with crushing, abrasion, impact and soundness value.

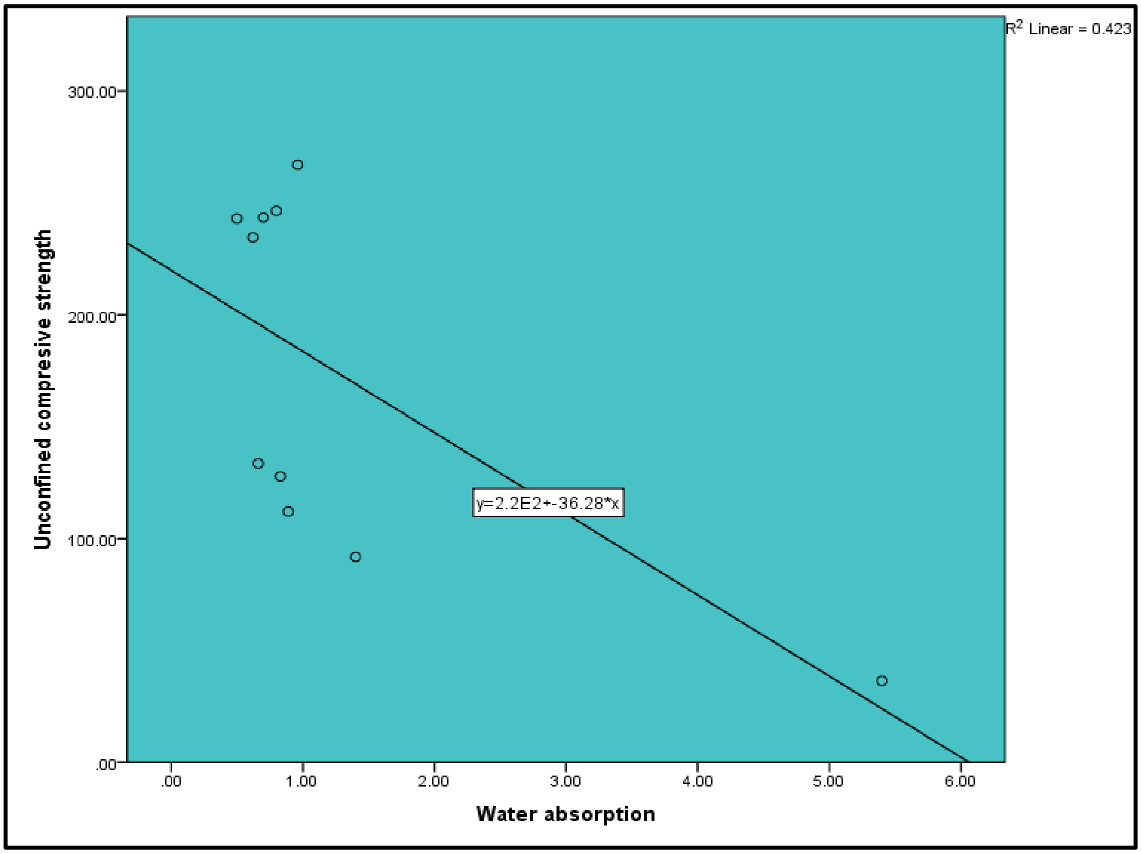

Figure 49 Unconfined compressive strength versus water absorption.

Table 18 Correlation of physical and mechanical properties

		Water absorption	Bulk density	Specific gravity	Flakiness index	Elongation index
Unconfined compressive strength	Pearson Correlation	-.651*	.982**	.960**	-.164	.857**
	Sig. (2-tailed)	.042	.000	.000	.652	.002
	N	10	10	10	10	10
Crushing value	Pearson Correlation	.926**	-.736*	-.837**	.103	-.683*
	Sig. (2-tailed)	.000	.015	.003	.778	.030
	N	10	10	10	10	10
Impact value	Pearson Correlation	.799**	-.948**	-.957**	.146	-.778**
	Sig. (2-tailed)	.006	.000	.000	.686	.008

	N	10	10	10	10	10
Abrasion value	Pearson Correlation	.698*	-.945**	-.951**	.335	-.881**
	Sig. (2-tailed)	.025	.000	.000	.344	.001
	N	10	10	10	10	10
Soundness value	Pearson Correlation	.766**	-.924**	-.963**	.299	-.887**
	Sig. (2-tailed)	.010	.000	.000	.402	.001
	N	10	10	10	10	10

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Unconfined compressive strength is inversely correlated with crushing, impact, abrasion and soundness value. Aggregates with higher compressive strength have shown low crushing, impact, abrasion and soundness value. Except from unconfined compressive strength other mechanical properties investigated in this study are directly related and positively correlated (Fig.50)

Table 19 correlation between mechanical properties

		Unconfined compressive strength	Crushing value	Impact value	Abrasion value	Soundness value
Unconfined compressive strength	Pearson Correlation	1	-.798**	-.959**	-.971**	-.951**
	Sig. (2-tailed)		.006	.000	.000	.000
	N	10	10	10	10	10
Crushing value	Pearson Correlation	-.798**	1	.882**	.816**	.895**
	Sig. (2-tailed)	.006		.001	.004	.000
	N	10	10	10	10	10
Impact value	Pearson Correlation	-.959**	.882**	1	.951**	.967**
	Sig. (2-tailed)	.000	.001		.000	.000
	N	10	10	10	10	10

Abrasion value	Pearson Correlation	-.971**	.816**	.951**	1	.979**
	Sig. (2-tailed)	.000	.004	.000		.000
	N	10	10	10	10	10
Soundness value	Pearson Correlation	-.951**	.895**	.967**	.979**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	10	10	10	10	10

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

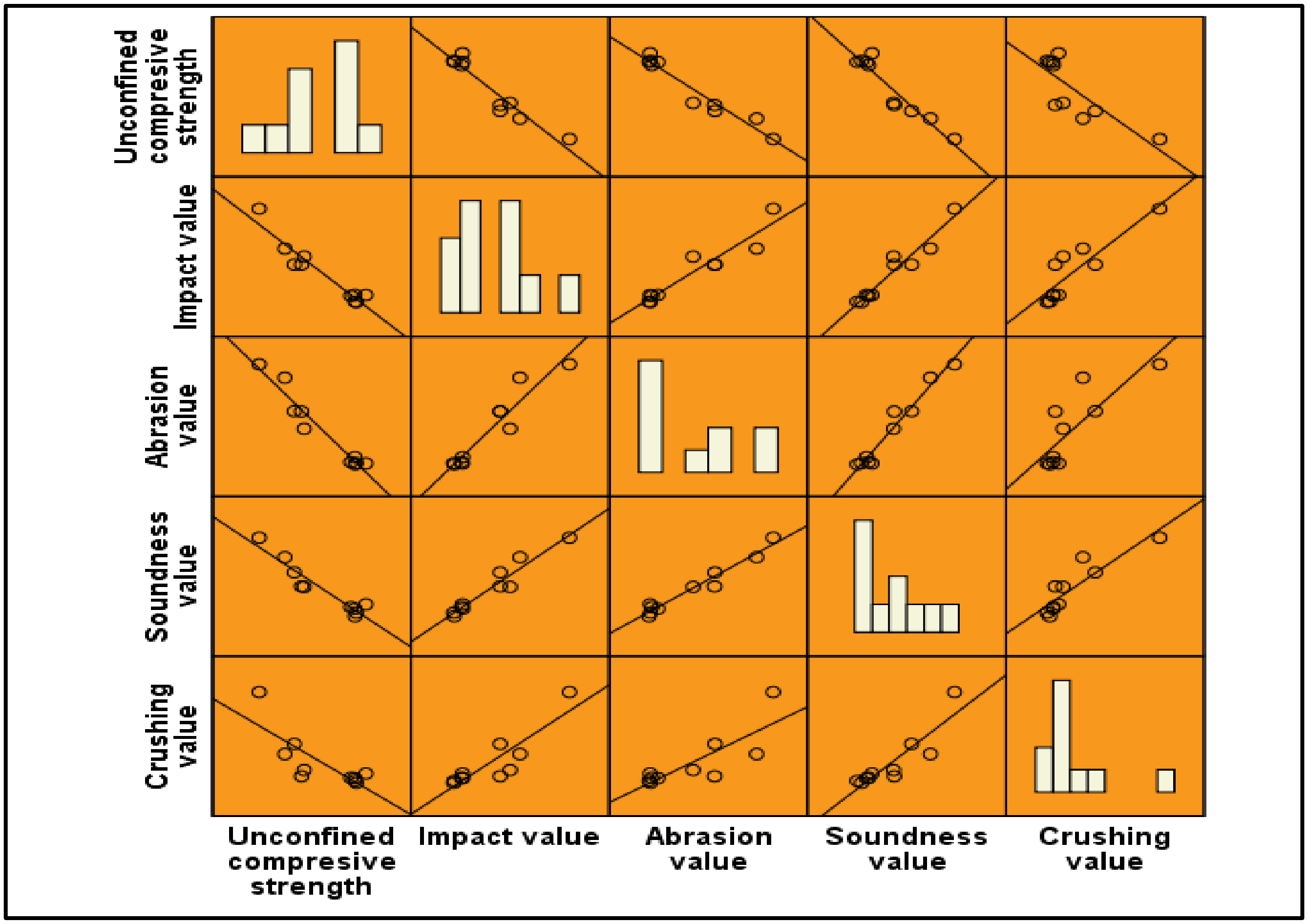

Figure 50 Relationships between mechanical properties

Chapter six

6. Conclusion and Recommendation

6.1 Conclusion

The demand of geological construction material is highly increasing in major cities as it is the main constituent for construction of roads, dams, bridges and other buildings. The geological material is extracted by quarrying operation. Nevertheless the activity causes major environmental and socio-economic impact if not managed well. Hence quarry sites should be located in suitable places that possess less socio-economic and environmental impact. Therefore in the present study seven governing factors for suitable quarry site selection were considered these are; lithology, land use land cover, distance to built up area, overburden thickness, distance to water bodies, distance to roads, relative relief and slope angle. The suitability selection involves numerous factors hence analytical hierarchy process (AHP) was used to determine the relative importance of factors considered and to determine the weight of each factors. The AHP is integrated with Arc GIS weighted overlay analysis to produce the preliminary quarry site suitability map.

The final quarry site suitability map showed that area of 598.4Km^2 (28.2%) is highly suitable for quarry site where as 25 % (543.2 Km^2) of the study area is unsuitable for quarry site. The unsuitable sites are covered with alluvium and eluvium deposits and are also settlements areas. The low suitable areas for quarry site selection account 34.6 %(735.6 Km^2) of the study area. In contrast the moderately suitable areas for suitable quarry site selection cover 246.7 Km^2 (11.6%) of the study area.

The rock materials in highly suitable areas for quarry selection were collected from 10 suitable quarry sites to assess their suitability for construction use. Physico-mechanical properties and mineral composition of the aggregates were investigated. Water absorption, specific gravity, Bulk density, aggregates shape test, unconfined compressive strength, crushing, abrasion, impact and soundness value test were conducted to validate the suitability of the aggregates for construction use. The finding showed that except the aggregates of quarry sites 4 and 5 all other aggregates fall within the physical and mechanical property specifications provided for construction use and are suitable for construction use. Nevertheless the qualitative assessment of alkali-silica reactivity by petrographic thin section analyses showed the presence of deleterious substance (reactive form of silica), beyond the specification provided in the basaltic aggregates from quarry 6, 7 and 8. However the finding cannot fully justify the potential alkali-silica reactivity of the aggregates hence, alkali-silica reactivity test should be conducted to quantify the alkali-silica reactivity of the aggregates.

The correlation between physico-mechanical and mineral composition was carried out. The unconfined compressive strength is positively correlated with plagioclase, pyroxene, olivine and opaque minerals whereas the crushing, abrasion, impact and soundness value are negatively correlated with these minerals. Except form unconfined compressive strength all other mechanical properties considered in this study has direct relationships. Water absorption is negatively correlated with unconfined compressive strength and positively correlated with other mechanical properties

6.2 Recommendation

Based on the finding of this study the following recommendations were forwarded.

- The suitable quarry site selection involves consideration of various factors to reduce socio-economic and environmental impacts associated with poor quarrying operation. Therefore, environmental planners are recommended to consider the impacts of quarrying activity and apply appropriate approaches to select the most suitable sites for quarrying operation.
- According to ASTM D 75 (1999), the validation of quarry site material for construction use needs a minimum of three samples to be tested from each quarry site. Nevertheless in this study due to financial and time constraints one representative sample was collected from each quarry site and assessed for their suitability in construction use. Therefore appropriate sampling is recommended to conduct detailed engineering property characterization of the aggregates before the quarry sites materials are used for construction purpose.
- In the study area quarry sites are selected without assessment of its environmental and socio- economic impact and the material are utilized for construction purpose regardless of their engineering quality for construction use which in turn may affect the long lasting performance of the structures. Therefore appropriate quarry site selection and characterization of crushed stone aggregates are recommended to reduce the socio-economic and environmental impact of the quarrying activity and to assure the suitability of the aggregates for construction use.
- The correlation analysis was carried out with small sample size (10 samples) and it is not very accurate to generalize the relationships of physic-mechanical and mineralogical compositions from this small sample size. Hence larger sample sizes are recommended to obtain statistically significant correlations.
- The petrographic thin section analyses was used to qualitatively assess the presence of deleterious substances, hence quantitatively alkali-silica reactivity test should be conducted to assess the potential alkali-silica reactivity of the aggregates.

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Appendixes

Appendix A point load strength and unconfined compressive strength

sample no	D mm	W1	W2	W Mm	D/W	Area mm	De2	De	Point load kN	point load N	Is Mpa	De/50	F	Is(50) Mpa	UCS (Mpa)
Q1Lm	39	46	50	48	0.8	1872	2383.5	48.82	12.37	12370	5.9	0.97	0.989	5.1	123
	35	37	50	43.5	0.8	1522.5	1938.5	44.03	9.227	9227	4.7	0.88	0.944	4.5	107
	36	55	49	52	0.69	1872	2383.5	48.82	10.54	10540	4.4	0.97	0.989	4.4	104
Q2Lm	34	65	45	55	0.61	1870	2381	48.8	9.07	9070	3.8	0.97	0.989	3.8	90
	42	48	56	52	0.8	2184	2780.8	52.73	15.12	15120	5.4	1.05	1.024	5.6	133
	32	48	44	46	0.69	1472	1874.2	43.29	14.7	14700	7.8	0.86	0.937	7.3	176
Q3Lm	35	65	55	60	0.58	2100	2673.8	51.71	14.55	14550	5.4	1.03	1.015	5.5	132
	40	48	56	52	0.76	2080	2648.3	51.46	12.61	12610	4.8	1.02	1.013	4.8	115
	39	40	52	46	0.84	1794	2284.2	47.79	13.12	13120	5.7	0.95	0.98	5.6	135
Q4Lm	42	45	60	52.5	0.8	2205	2807.5	52.99	4.43	4430	1.6	1.06	1.026	1.6	38
	43	60	56	58	0.74	2494	3175.5	56.35	5.37	5370	1.7	1.13	1.055	1.8	42
	44	48	58	53	0.83	2332	2969.2	54.49	3.2	3200	1.	1.09	1.039	1.1	26
Q5Lm	31	30	34	32	0.96	992	1263.1	35.54	6.42	6420	5.1	0.7	0.858	4.3	104
	38	38	42	40	0.95	1520	1935.3	43.99	9.02	9020	4.7	0.88	0.944	4.4	105
	38	40	45	42.5	0.89	1615	2056.3	45.35	5.85	5850	2.8	0.9	0.957	2.7	65
Q6Bslt	50	48	56	52	0.96	2600	3310.4	57.54	36.4	36400	10.1	1.15	1.065	11.7	281
	52	46	60	53	0.98	2756	3509	59.24	37.5	37500	10.7	1.18	1.079	11.5	276
	53	50	70	60	0.88	3180	4048.9	63.63	36.8	36800	9.1	1.3	1.115	10.1	24
Q7Bslt	50	50	60	55	0.90	2750	3501.4	59.17	33.4	33400	9.5	1.2	1.079	10.3	246
	48	52	58	55	0.87	2640	3361.4	57.98	32.1	32100	9.5	1.15	1.069	10.2	244
	52	50	70	60	0.86	3120	3972.5	63.03	31.6	31600	7.9	1.26	1.11	8.8	211
Q8Bslt	54	46	74	60	0.9	3240	4125.3	64.23	34.6	34600	8.4	1.28	1.119	9.4	225
	48	50	58	54	0.88	2592	3300.2	57.45	31.4	31400	9.5	1.14	1.064	10.1	243

	47	48	56	52	0.90	2444	3111.8	55.78	32.3	32300	10.4	1.1	1.05	10.9	261
Q9Bslt	55	58	70	64	0.85	3520	4481.8	66.95	42.8	42800	9.5	1.3	1.14	10.9	261
	60	60	76	68	0.88	4080	5194.8	72.08	39.8	39800	7.7	1.4	1.179	9.03	216
	54	56	64	60	0.9	3240	4125.3	64.23	40.1	40100	9.7	1.3	1.119	10.9	261
Q10Bslt	52	50	62	56	0.92	2912	3707.7	60.89	33.6	33600	9.1	1.23	1.093	9.9	237
	50	53	65	59	0.8	2950	3756.1	61.29	35.8	35800	9.5	1.2	1.096	10.4	250
	48	50	70	60	0.8	2880	3666.9	60.56	33.8	33800	9.2	1.2	1.09	10	241

Q= quarry Lm= limestone Bslt= Basalt

Appendix B Bulk density

sample no	Trial	mass of container gram	volume of con cm3	mass of container + sample gram	mass of sample gram	Bulk Density in Kg
Q1Lm	1	3952	5026.5	14298	10346	2058.3
	2	3952	5026.5	14283	10331	2055.3
Q2Lm	1	3952	5026.5	14221	10269	2043
	2	3952	5026.5	14238	10286	2046.3
Q3Lm	1	3952	5026.5	14176	10224	2034.
	2	3952	5026.5	14195	10243	2037.8
Q4 Lm	1	3952	5026.5	13535.5	9583.5	1906.5
	2	3952	5026.5	13555	9603	1910.7
Q5Lm	1	3952	5026.5	14085	10133	2016
	2	3952	5026.5	14080	10128	2015
Q6Bslt	1	3952	5026.5	15679	11727	2333
	2	3952	5026.5	15669	11717	2331
Q7Bslt	1	3952	5026.5	15605	11653	2318.3
	2	3952	5026.5	15805	11853	2358.1
Q8Bslt	1	3952	5026.5	15831	11879	2363.3
	2	3952	5026.5	15840	11888	2365
Q9Bslt	1	3952	5026.5	15847	11895	2366.4
	2	3952	5026.5	15839	11887	2364.9
Q10Bslt	1	3952	5026.5	15731	11779	2343.4
	2	3952	5026.5	15727	11775	2342.6

Q=quarry Lm= Limestone Bslt= Basalt

Appendix C water absorption and specific gravity

sample Id	trial	initial weight	weight of oven dried sample(A)	weight of saturated surface dry(B)	Apparent mass (C)	water absorption (B-A/A*100)	Specific gravity (B/B-C)
Q1Lm	1	2212	2206	2217.5	1358	0.52	2.6
	2	3006.5	3000	3037.5	1877	1.25	2.6
Q2Lm	1	2207	2200	2217.5	1387.5	0.8	2.7
	2	3004	2999	3014.5	1889	0.52	2.7
Q3Lm	1	2178.5	2170	2191.5	1368.5	0.99	2.4
	2	3014	3007.5	3027.5	1888	0.67	2.7
Q4 Lm	1	2306	2294	2423.5	1436.5	5.65	2.5
	2	3017	3007.5	3164.5	1883	5.2	2.5
Q5Lm	1	2156.5	2150	2184.5	1344	1.60	2.6
	2	3003.5	2995.5	3035.5	1862	1.34	2.6
Q6Bslt	1	2239	2230	2249.5	1474.5	0.87	2.9
	2	3010.5	2988.5	3020	1968	1.0	2.9
Q7Bslt	1	2123	2115	2127.5	1395.5	0.59	2.9
	2	3008	2998	3017.5	1980	0.65	2.9
Q8Bslt	1	2221	2214	2228.5	1459.5	0.65	2.9
	2	3017	3007.5	3030.5	1983	0.76	2.9
Q9Bslt	1	2220	2216.5	2232.5	1453.5	0.72	2.9
	2	3008.5	3003.5	3030.5	1983	0.9	2.9
Q10Bslt	1	2225	2217	2225.5	1450	0.38	2.9
	2	3011	2986	3004	1969.5	0.60	2.9
Q=quarry Lm= Limestone Bslt= Basalt							

Appendix D Aggregate crushing value

sample ID	Trial	Mass of test sample 14 pass 10mm retain gram(A)	mass of sample retained on 2.36mm sieve	mass of sample passing on 2.36mm sieve(B)	Aggregate crushing value% (B/A*100)
Q1Lm	1	2137	1545	585	27.4
	2	2144	1559	579	27
Q2Lm	1	2670	2175	487	18.2
	2	2586	2125	455	17.6
Q3Lm	1	2650	2230	413	15.6
	2	2657	2232	419	15.8
Q4 Lm	1	3025	1610	1408	46.5
	2	2900	1589	1303	44.9
Q5Lm	1	2610	1984	620	23.8
	2	2600	1980	613	23.6
Q6Bslt	1	2588	2158	425	16.4
	2	2610	2168	438	16.8
Q7Bslt	1	2650	2242	402	15.2
	2	2654	2246	402	15.1
Q8Bslt	1	2594	2226	363	14
	2	2590	2220	366	14.1
Q9Bslt	1	2610	2259	346	13.3
	2	2594	2243	347	13.4
Q10Bslt	1	2622	2234	384	14.6
	2	2628	2219	404	15.4
Q=quarry Lm= Limestone Bslt= Basalt					

Appendix E Aggregate Impact value

sample Id	Trial	Mass of Test sample 14mm pass and 10mm retain in gram(A)	mass of sample retained on 2.36mm sieve gram	mass of sample passing on 2.36mm sieve(B) gram	Aggregate Impact value% (B/A*100)
Q1Lm	1	601.5	526.5	74	12.3
	2	592	520.5	71	12
	3	585	515.5	69	11.8
Q2Lm	1	615.5	529	86	14
	2	587.5	506	80.5	13.7
	3	619.5	535.5	83.5	13.5
Q3Lm	1	614.5	534.5	80	13.0
	2	620	544.5	74.5	12.0
	3	616.5	539	77	12.5
Q4Lm	1	564	455.5	108	19.1
	2	568	455	112	19.7
	3	565.5	456	108.5	19.2
Q5Lm	1	633	542	90.5	14.3
	2	627.5	545	82	13.1
	3	634.5	541	93	14.7
Q6Bslt	1	639.5	586	52.5	8.2
	2	627	577	49.5	7.9
	3	634.5	579	55	8.7
Q7Bslt	1	649	600	48	7.4
	2	637.5	582.5	54.5	8.5
	3	635.5	580	55	8.7
Q8Bslt	1	641.5	592.5	48	7.5
	2	627.5	580	46.5	7.4
	3	635.5	589	46	7.2
Q9Bslt	1	651.5	605	46	7.1
	2	647.5	598.5	48	7.4
	3	649.5	600	49	7.5
Q10Bslt	1	629.5	575.5	53	8.4
	2	645.5	596.5	48.5	7.5
	3	641.5	585	56	8.7
Q=quarry Lm= Limestone Bslt= Basalt					

Appendix F aggregate abrasion value

sample no	trial	mass of test sample(A) gram	material retain on sieve 1.7mm(B) gram	material passing sieve 1.7mm(C) gram	Los Angeles abrasion value % (C/A*100)
Q1Lm	1	5000	3666.5	1314.5	26.3
	2	5000	3656	1330	26.6
Q2Lm	1	5000	3905	1079	21.6
	2	5000	3897	1091.5	21.8
Q3Lm	1	5000	3661	1326	26.5
	2	5000	3675.5	1309.5	26.1
Q4 Lm	1	5000	3041.5	1941	38.8
	2	5000	3030	1958	39.1
Q5Lm	1	5000	3235	1751.5	35.0
	2	5000	3222	1763	35.3
Q6Bslt	1	5000	4352	627.5	12.6
	2	5000	4361	619.5	12.4
Q7Bslt	1	5001.5	4336	643	12.9
	2	5000	4350.5	632.5	12.7
Q8Bslt	1	5000	4387	598	12
	2	5000	4363	619	12.4
Q9Bslt	1	5000	4359.5	622.5	12.5
	2	5000	4351.5	631.5	12.6
Q10Bslt	1	5000	4266	716	14.32
	2	5000	4289	698	13.96
Q=quarry Lm= Limestone Bslt= Basalt					

Appendix G aggregate soundness value

sample ID	Test sample used		grading of the test sample %(A)	mass of test sample(B)	mass retaining on designated sieve after test(C)	percentage loss(C) (A-B)/A*100	weighted percentage lost (A*C)/100
	Passing sieve mm	Retaining on sieve mm					
Q1Lm	37.5	19	53.60199715	1503	1402	6.719893546	3.601997147
	19	9.5	35.69900143	1001	841	15.98401598	5.706134094
	9.5	4.75	10.69900143	300	262	12.66666667	1.355206847
		Total	100	2804		Soundness value	10.7
sample Id	passing sieve no	retaining on sieve	grading of the test sample (A)	mass of test sample(B)	mass retaining on designated sieve after test(C)	percentage loss(C) (A-B)/A*100	weighted percentage lost (A*C)/100
Q2Lm	37.5	19	53.54976811	1501	1425	5.063291139	2.711380664
	19	9.5	35.74741349	1002	878.5	12.3253493	4.405993578
	9.5	4.75	10.70281841	300	272	9.333333333	0.998929718
		total	100	2803			8.1
sample Id	passing sieve no	retaining on sieve	grading of the test sample (A)	mass of test sample(B)	mass retaining on designated sieve after test(C)	percentage loss(C) (A-B)/A*100	weighted percentage lost (A*C)/100
Q3Lm	37.5	19	53.63506771	1505	1420.5	5.61461794	3.011404134
	19	9.5	35.67355666	1001	886.5	11.43856144	4.080541696
	9.5	4.75	10.69137562	300	268	10.66666667	1.1404134
		Total	100	2806		Soundness value	8.2
sample Id	passing sieve no	retaining on sieve	grading of the test sample (A)	mass of test sample(B)	mass retaining on designated sieve after test(C)	percentage loss(C) (A-B)/A*100	weighted percentage lost (A*C)/100
Q4Lm	37.5	19	53.55230275	1500	1315	12.33333333	6.604784006
	19	9.5	35.7372367	1001	783	21.8	7.790717601
	9.5	4.75	10.71046055	300	230	23.33333333	2.499107462
		Total	100	2801		Soundness value	16.9
sample	passing	retaining	grading of	mass of	mass retaining	percentage	weighted

ID	sieve no	on sieve	the test sample (A)	test sample(B)	on designated sieve after test(C)	loss(C) (A-B)/A*100	percentage lost (A*C)/100
Q5Lm	37.5	19	53.54723708	1502	1403	6.591211718	3.529411765
	19	9.5	35.75757576	1003	791	21.13659023	7.557932264
	9.5	4.75	10.69518717	300	235	21.66666667	2.317290553
		Total	100	2805		Soundness value	13.4
sample Id	passing sieve no	retaining on sieve	grading of the test sample (A)	mass of test sample(B)	mass retaining on designated sieve after test(C)	percentage loss(C) (A-B)/A*100	weighted percentage lost (A*C)/100
Q6Blst	37.5	19	53.51409204	1500	1450	3.333333333	1.783803068
	19	9.5	35.78308955	1003	933	6.979062812	2.497324295
	9.5	4.75	10.70281841	300	278	7.333333333	0.78487335
		Total	100	2803		Soundness value	5.1
sample Id	passing sieve no	retaining on sieve	grading of the test sample (A)	mass of test sample(B)	mass retaining on designated sieve after test(C)	percentage loss(C) (A-B)/A*100	weighted percentage lost (A*C)/100
Q7Blst	37.5	19	53.63506771	1505	1458	3.122923588	1.674982181
	19	9.5	35.67355666	1001	940	6.093906094	2.173913043
	9.5	4.75	10.69137562	300	281	6.333333333	0.677120456
		Total	100	2806		Soundness value	4.5
sample ID	passing sieve no	retaining on sieve	grading of the test sample (A)	mass of test sample(B)	mass retaining on designated sieve after test(C)	percentage loss(C) (A-B)/A*100	weighted percentage lost (A*C)/100
Q8Blst	37.5	19	53.48422741	1500.5	1474	1.766077974	0.94457316
	19	9.5	35.82249153	1005	963.5	4.129353234	1.479237213
	9.5	4.75	10.69328106	300	288	4	0.427731242
		Total	100	2805.5		Soundness value	2.9
sample ID	passing sieve no	retaining on sieve	grading of the test sample (A)	mass of test sample(B)	mass retaining on designated sieve after test(C)	percentage loss(C) (A-B)/A*100	weighted percentage lost (A*C)/100

Q9Bslt	37.5	19	53.60199715	1503	1465	2.52827678	1.355206847
	19	9.5	35.69900143	1001	960	4.095904096	1.462196862
	9.5	4.75	10.69900143	300	280	6.666666667	0.713266762
		Total	100	2804		Soundness value	3.5
sample Id	passing sieve no	retaining on sieve	grading of the test sample (A)	mass of test sample(B)	mass retaining on designated sieve after test(C)	percentage loss(C) (A-B)/A*100	weighted percentage lost (A*C)/100
Q10Bslt	37.5	19	53.54976811	1501	1463	2.53164557	1.355690332
	19	9.5	35.74741349	1002	945.5	5.638722555	2.015697467
	9.5	4.75	10.70281841	300	277	7.666666667	0.820549411
		Total	100	2803		Soundness value	4.2
Q=quarry Lm= Limestone Bslt= Basalt							

Appendix H1 flakiness and elongation index of aggregates from quarry 1

Sample ID	Grading of test sample		Mass of test sample gram Trial		Mass of flaky particles		Mass of elongated particles	
Q1Lm	Passing sieve	Retaining sieve	1	2	Trail 1	Trail 2	Trial 1	Trial 2
	63mm	50mm	0	0				
	50mm	37.5mm	200	0				
	37.5mm	28mm	350	0				
	28mm	20mm	3712.5	4005	1074.5	1113	68	72
	20mm	14mm	2008.5	2003	379.5	365	284.5	298
	14mm	10mm	1005	1001	169	178	209	198
	10mm	6.3	500	503	79	85	98	75
	Total (M1)		7776		Total m3 1702	1741	659.5	643
	Total (M2)		7226	7512	-	-		
Individual mass of 5% or less than of total mass (M1) are Discarded and other are summed up and recorded as M2.				Flakiness index (M2/M3)*100	23.6	23.2		
				Elongation index (M3/M2)*100			9.1	8.56

Appendix H2 flakiness and elongation index of aggregates from quarry 2

Sample ID	Grading of test sample		Mass of test sample gram Trial		Mass of flaky particles gram		Mass of elongated particles gram	
					Trail		Trial	
Q2Lm	Passing sieve	Retaining sieve	1	2	1	2	1	2
	63mm	50mm						
	50mm	37.5mm	200					
	37.5mm	28mm	4003	4005	575	4005	194	200.5
	28mm	20mm	2009	2003	415	2003	225.5	219
	20mm	14mm	1023	1010.5	124.5	1010.5	349	359.5
	14mm	10mm	500	500	96.5	500	268	258
	10mm	6.3	500	500	109	500	152	203
	Total (M1)		8235		Total m3 1320		1188.5	1240
	Total (M2)		8035	8018.5	-	8018.5		
Individual mass of 5% or less than of total mass (M1) are Discarded and other are summed up and recorded as M2.				Flakiness index (M2/M3)*100	16.4	16		
				Elongation index (M3/M2)*100			14.78	15.45

Appendix H3 flakiness and elongation index of aggregates from quarry 3

Sample ID	Grading of test sample		Mass of test sample gram		Mass of flaky particles g			Mass of elongated particles g	
			Trial						
Q3Lm	Passing sieve	Retaining sieve	1	2	Trail			Trial	
					1		2	1	2
	63mm	50mm	0						
	50mm	37.5mm	155						
	37.5mm	28mm	4006	4003.5	1125.5		1189	318	301
	28mm	20mm	2006	2005.5	518		498	265	278
	20mm	14mm	1003	1002	181		192	192	181
	14mm	10mm	503.5	501.5	161.5		171	202	193
	10mm	6.3	500.5	500	186		201	186	193
	Total (M1)		8174		Total m3	2172	2251	1163	1146
	Total (M2)		8019	8012.5					
Individual mass of 5% or less than of total mass (M1) are Discarded and other are summed up and recorded as M2.				Flakiness index% (M2/M3)*100	27		28.1		
				Elongation index% (M3/M2)*100				14.5	14.3

Appendix H4 flakiness and elongation index of aggregates from quarry 4

Sample ID	Grading of test sample		Mass of test sample gram		Mass of flaky particles g		Mass of elongated particles g	
			Trial					
Q4Lm	Passing sieve	Retaining sieve	1	2	Trail		Trial	
					1	2	1	2
	63mm	50mm	0	0				
	50mm	37.5mm	232	0				
	37.5mm	28mm	1060	0	201.5		39	
	28mm	20mm	4003.5	4001.5	1233	1320	90.5	106
	20mm	14mm	2001	2005.5	247.5	308	219.5	245
	14mm	10mm	1010	100.5	89.5	71	296.5	263.5
	10mm	6.3	502.3	505.5	115	120.5	101	89.5
	Total (M1)		8808.8		Total m3 1886.5	1819.5	746.5	704
	Total (M2)		8576.8	6613				
Individual mass of 5% or less than of total mass (M1) are Discarded and other are summed up and recorded as M2.				Flakiness index% (M2/M3)*100		22	27.5	
				Elongation index% (M3/M2)*100			8.7	10.6

Appendix H5 flakiness and elongation index of aggregates from quarry 5

Sample ID	Grading of test sample		Mass of test sample gram		Mass of flaky particles g		Mass of elongated particles g	
			Trial					
Q5Lm	Passing sieve	Retaining sieve	1	2	Trail		Trial	
					1	2	1	2
	63mm	50mm						
	50mm	37.5mm						
	37.5mm	28mm	450.5		35		12	
	28mm	20mm	4015.5	4002.5	2409	2005.5	15	35
	20mm	14mm	2005.5	2000	866	789	77	61
	14mm	10mm	1000	1015	159	135	225	283
	10mm	6.3	505.5	500.5	172	153	130	157
	Total (M1)				Total m3 3641	3082.5	459	536
	Total (M2)		7977	7518				
Individual mass of 5% or less than of total mass (M1) are Discarded and other are summed up and recorded as M2.				Flakiness index% (M2/M3)*100	45.6	41		
				Elongation index% (M3/M2)*100			5.8	7.1

Appendix H6 flakiness and elongation index of aggregates from quarry 6

Sample ID	Grading of test sample		Mass of test sample gram Trial		Mass of flaky particles g		Mass of elongated particles g	
Q6Blst	Passing sieve	Retaining sieve	1	2	Trail 1	2	Trial 1	2
	63mm	50mm						
	50mm	37.5mm	1749		358.5		277	
	37.5mm	28mm	596		178.5		266	
	28mm	20mm	2001	2008.5	832.5	783	112.5	138
	20mm	14mm	1002	1015	277.5	309	229	209
	14mm	10mm	503	517	183.5	192	147	159
	10mm	6.3	500	500	203	171	98	162
	Total (M1)		6351	4040.5	Total m3 2033.5	1455	1129.5	668
	Total (M2)		6351	4040.5				
Individual mass of 5% or less than of total mass (M1) are Discarded and other are summed up and recorded as M2.				Flakiness index% (M2/M3)*100	32.01857975	36		
				Elongation index% (M3/M2)*100			17.8	16.5

Appendix H7 flakiness and elongation index of aggregates from quarry 7

Sample ID	Grading of test sample		Mass of test sample gram Trial		Mass of flaky particles g		Mass of elongated particles g	
Q6Blst	Passing sieve	Retaining sieve	1	2	Trail 1	Trail 2	Trial 1	Trial 2
	63mm	50mm	0					
	50mm	37.5mm	250	4003.5				
	37.5mm	28mm	4007.5	2001.5	551	601	587	603
	28mm	20mm	2002.5	1006.5	648	712	99	113
	20mm	14mm	1004.5	500	283.5	309	249	211
	14mm	10mm	501	503	147	128	235	352
	10mm	6.3	502.5	4003.5	168	153	153	171
	Total (M1)		8268	8014.5	Total m3 1797.5	1903	1323	1450
	Total (M2)		8018	8014.5				
Individual mass of 5% or less than of total mass (M1) are Discarded and other are summed up and recorded as M2.				Flakiness index% (M2/M3)*100	22.4	23.7		
				Elongation index% (M3/M2)*100			16.5	18.1

Appendix H8 flakiness and elongation index of aggregates from quarry 8

Sample ID	Grading of test sample		Mass of test sample gram Trial		Mass of flaky particles g		Mass of elongated particles g	
Q6Blst	Passing sieve	Retaining sieve	1	2	Trail 1	2	Trial 1	2
	63mm	50mm	0	0				
	50mm	37.5mm	1235	0	68.5		21	
	37.5mm	28mm	4011.5	4005.5	1317	1393	595	557
	28mm	20mm	2000.5	2005.5	644	597	331	309
	20mm	14mm	1002	1001.5	271.5	303	360	379
	14mm	10mm	504	504	74	121	315	298
	10mm	6.3	502	500.5	112	133	193	181
	Total (M1)		9255	8017	Total m3 2487	2547	1815	1724
	Total (M2)		9255	8017				
Individual mass of 5% or less than of total mass (M1) are Discarded and other are summed up and recorded as M2.				Flakiness index% (M2/M3)*100	26.9	31.8		
				Elongation index% (M3/M2)*100			19.6	21.5

Appendix H9 flakiness and elongation index of aggregates from quarry 9

Sample ID	Grading of test sample		Mass of test sample gram		Mass of flaky particles g		Mass of elongated particles g	
			Trial					
Q6Blst	Passing sieve	Retaining sieve	1	2	Trail		Trial	
					1	2	1	2
	63mm	50mm	0	0				
	50mm	37.5mm	1838	0	0		187.5	
	37.5mm	28mm	2191	4000	422.5	1012	694.5	1059
	28mm	20mm	2012.5	2001.5	534.5	549	29	61
	20mm	14mm	1006	1005	163.5	149	332.5	281
	14mm	10mm	504	503	109	103	23	31
	10mm	6.3	500	501.5	137	149.5	17	21
	Total (M1)		8051.5	8011	Total m3 1366.5	1962.5	1283.5	1453
	Total (M2)		8051.5	8011				
Individual mass of 5% or less than of total mass (M1) are Discarded and other are summed up and recorded as M2.				Flakiness index% (M2/M3)*100	17	24.5		
				Elongation index% (M3/M2)*100			15.9	18.1

Appendix H10 flakiness and elongation index of aggregates from quarry 10

Sample ID	Grading of test sample		Mass of test sample gram		Mass of flaky particles g		Mass of elongated particles g	
			Trial					
Q6Blst	Passing sieve	Retaining sieve	1	2	Trail		Trial	
					1	2	1	2
	63mm	50mm	0	0				
	50mm	37.5mm	1646	0	89.5		0	
	37.5mm	28mm	3509.5	3000	415	389	694.5	571
	28mm	20mm	2004	2003.5	559.5	403	423.5	309
	20mm	14mm	1000.5	1009.5	193.5	171	394	323
	14mm	10mm	504.5	500	154	139	242	196
	10mm	6.3	503	501	173	161	189	157
	Total (M1)		9167.5	7014	Total m3 1584.5	1263	1943	1556
	Total (M2)		9167.5	7014				
Individual mass of 5% or less than of total mass (M1) are Discarded and other are summed up and recorded as M2.				Flakiness index% (M2/M3)*100	17.3	18		
				Elongation index% (M3/M2)*100			21.2	22.2