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Engineering and Mineralogical Assessment of Coarse Aggregates used in District Mardan

Fareeha Malahat[1], Amjad Naseer[2] and Rubina Bilqees[3*]
[1]*Communication & Works Department, Khyber Pakhtunkhwa*
[2]*University of Engineering & Technology Peshawar, Pakistan*
[3]*National Centre of Excellence in Geology, University of Peshawar, Pakistan*
**Corresponding author's email:* rubinabilqees@gmail.com
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Abstract

There are various potential aggregate sources available in Pakistan's Northern and Western regions but few have been tested for their suitability as per the international standards. In this study six quarries from Mardan district have been selected to evaluate for use as coarse aggregate in concrete construction. The aggregate from the six quarries selected is already being widely used in Mardan area but no research studies have been carried out. The results of the study showed that the samples from Palai crush fulfills all the specifications that an international standard for aggregates demands. Therefore, it is almost compatible with that of Margalla crush and can be used as an alternate source of Margalla crush. Besides, the crush from Maneri, Sawaldher and Shamozai are also recommended for use in ordinary structural concrete with some limitations.

Keywords: Engineering; Assessment; Aggregate; Limestone; Mardan.

1. Introduction and Literature Review

Concrete is a composite material which is obtained by mixing together cement paste and aggregates, both coarse and fine. The term "Construction aggregate" or "aggregate" is a broadly used for coarse to medium grained particulate material, most commonly, of sand, gravel, crushed stone, slag, recycled concrete and geosynthetic aggregates. Aggregates are natural materials or non-natural ones depending upon the source from where these are extracted (ACI Education Bulletin E1-2007). Aggregates are the most mined materials in the world that serve as reinforcement to add strength to the overall composite material. Besides these provide bulk volume and make the concrete cost effective. As the aggregates occupy more than three-fourth of the concrete volume, hence, their physico-mechanical, chemical and mineralogical characteristics greatly affect the quality of concrete (Neville, 2000). The properties of aggregates, if are not up to the required standards, might critically produce bad manifestations like alkali-silica/ alkali-carbonate reactions/ physical effects that compromise the strength of concrete which consequently deteriorate the quality of construction (Lopez-Buendia et al., 2006).

Limestone is extremely valuable raw material used in a wide range of industries but the cement and construction industries are the main consumers. Strategic evaluation of regional or local limestone resources need to involve the physical, mechanical, chemical and mineralogical properties of the stone. It is the main source of coarse aggregate in construction industry. There are huge resources of this rock in Khyber Pakhtunkhwa province. Limestone from various localities of Khyber Pukhtunkhwa have been studied to evaluate them for use in various industries including construction (Bilqees and Shah, 2007, Jan et al., 2009 and Bilqees et al., 2012). Imtiaz ul Haq (2012) has studied various engineering properties of some limestone quarries in District Nowshera, KPK in order to find suitable material for aggregates locally available at Nowshera and minimize the dependence on Margalla crush which has been extensively used due to its good quality suitable for construction (Gondal et al., 2009; Ghaffar et al., 2010). Aggregates from Allai area were studied for reconstruction and rehabilitation of buildings affected by the deadly earthquake of October, 2005 (Iqbal et al., 2009). Furthermore, the effect on the durability of freezing and thawing on coarse aggregate concrete was done by V.R Schaefer, J.T Keven and K.Wang (October, 2009).

The Margalla hills lie nearby the capital city Islamabad which is being affected by environmental issues associated with mining, like blasting and crushers operating in the mining area. Besides environmental issues, one big problem is that this quarry is depleting very rapidly and there is a need to discover new resources of aggregates. Therefore, the aim of this study is to search for more aggregate sources in Peshawar region to find alternative of Margalla crush and to economize the concrete construction by reducing transportation charges from far flung areas. Therefore, six queries from Mardan area have been selected for the present work. Mardan district lies between latitude 34 05 to 34 32 North and longitude 71 48 to 72 25 East. It is bounded to the north –east by district Buner, on the north-west by Malakand, on the south-east by Swabi district, on the south by Nowshera district and on the west by Charssada district. Though the aggregate material is already being mined from the study areas but no research work has been done to evaluate the quality of the resource. The quality of concrete is dependent on the aggregate material therefore, the characterization of aggregate is very important especially for the construction of mega structures (Fookes et al., 1988; Ahsan et al., 2000).

2. Methodology

2.1. Field Work

Field work was carried out for the investigation and assessment of coarse aggregate source material and the work was limited to the aggregates of the quarries that are being widely used in District Mardan. The location of all the quarries are marked in Fig 1 except that of Margalla which was sampled for comparison sake only.

2.2 Sampling

The representative samples from the quarries were collected by using ASTM D-75 where applicable. Minimum mass recommended as per ASTM D-75 were collected from conveyor belts, flowing bins and stockpiles in equal increments. The list of available quarries and their status of selection for this research study is listed in table 1.

1. The samples were then transported to the concerned laboratories for testing and evaluation (UET Peshawar Soil and Concrete lab, MCE, Risalpur Geotecnical laboratory, Petrographic and Geochemistry labs, NCE in Geology, University of Peshawar). The following tests were conducted

2. *Physical/Mechanical Tests*
   a. Bulk Density Test (ASTM C 29)
   b. Specific Gravity & Water Absorption Test (ASTM C 127-07)
   c. Flakiness & Elongation index (BS 812 Section 105.1 and 105.2)
   d. Aggregate Soundness Test (ASTM C88)
   e. Aggregate Crushing Value (BS 812 Part 110)
   f. Aggregate Impact Value (BS 812 Part 112)
   g. Los Angeles Abrasion Value (ASTM C 131)

3. *Chemical/Mineralogical Tests*
   a. Potential of Alkali-Silica Reaction (ASTM C 289)
   b. Petrographic Examination of aggregate for concrete (ASTM C 295)

4. *Concrete Tests*
   a. Compressive Strength of Cylinders (ASTM C 39-04)

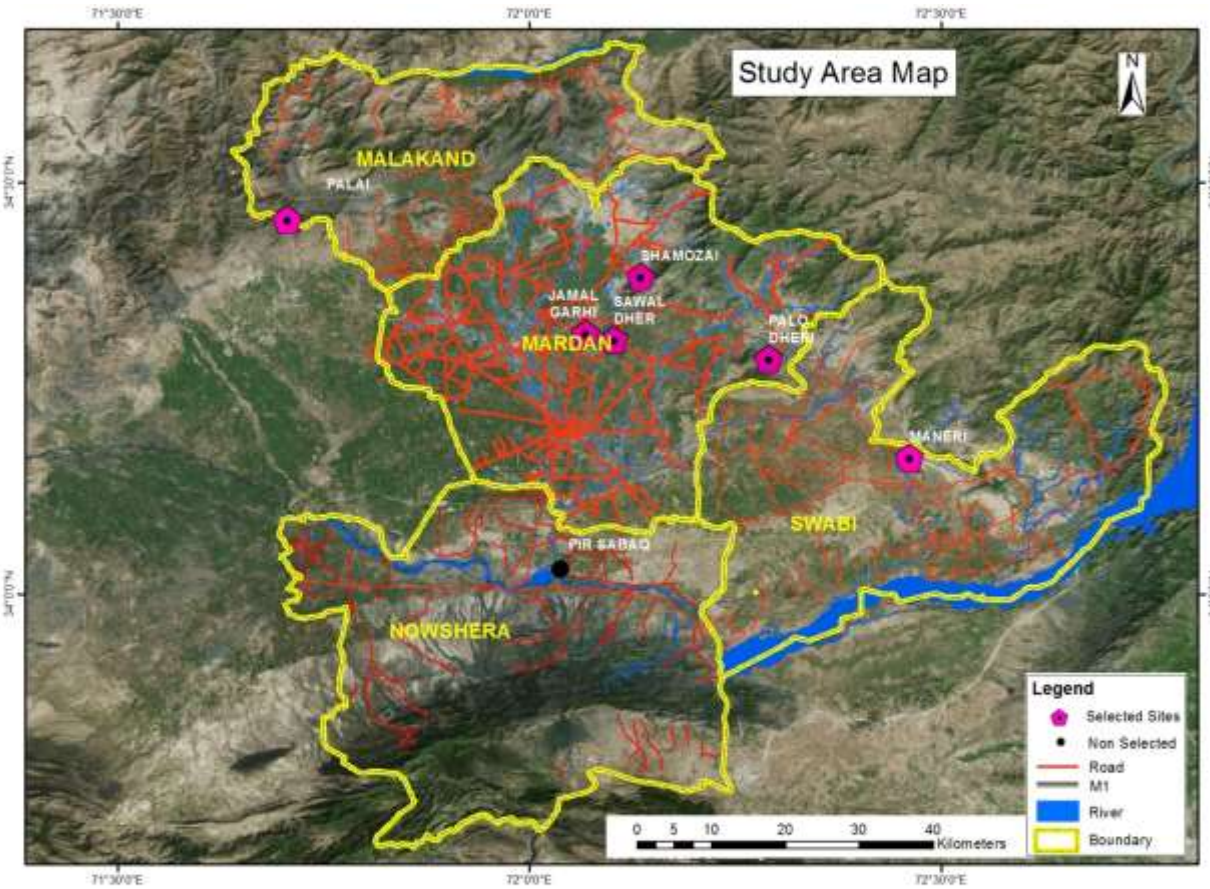


Fig. 1. Research Area Map (Retrieved from Google maps).

Table 1. Quarries whose material is being used in Mardan District.

Quarry Site Location	**Status of Selection of Quarry**
Sawaldher, Mardan	Selected
Palodheri, Mardan	Selected
Babuzai/Shamozai, Mardan	Selected
Jamal Garhi, Mardan	Selected
Pir Sabaq, Nowshera	Not Selected (Has been already investigated)
Palai, Malakand	Selected
Maneri, Swabi	Selected
Margalla, Taxilla	Selected

3. Results and Discussions

3.1 Bulk Density

This test was performed according to ASTM C 39 and it is found that all the studied specimen are normal weight aggregates and the Bulk density ranges from 70 pcf to 1120 pcf (1120 to 1920 kg/m3) ASTM C 125-03.

3.2. Specific Gravity & Water Absorption

The specific gravity of aggregates is determined in various moisture conditions of aggregate; 1) when water is filled in all the apertures of aggregate, but still its surface is dry then it is called saturated surface dry condition (SSD), 2) the aperture water is lost by drying it in air then it is called air dry condition (AD) and when all the moisture is removed by drying the aggregate in an oven, then this condition of the aggregate is called bone dry or oven dry (OD) condition (Fig. 2).

This test was carried out according to ASTM C 127. The bulk specific gravity of Normal weight aggregates is 2.4-3.0 (ASTM C 125 -03), which show that specimen from all the quarries are normal weight aggregates. Whereas, the water absorption value of Jamal Garhi aggregates is 2% which is greater as compared to those for the other quarries samples.

3.3. Shape & Texture

The shape and surface texture of coarse aggregates are significant features because they mainly affect the compaction, workability and stress resistance. The use of rounded and smooth aggregates enhances the workability of the concrete and have better bond characteristics (Shetty, 2010). On the other hand the rough, flaky, angular or elongated aggregates reduces its workability. This test was performed as per BS: 105.1 & 105.2, respectively, by mass. The results showed that Flakiness Index (FI) & Elongation Index (EI) of samples from most of the quarries were within permissible limit of the international standards but FI for Sawaldher is 25.9 and EI for Jamal Garhi is 31 which are more than those of other quarries (Table-2).

3.4. Soundness

Soundness of aggregates is its ability to bear all the weather conditions including freeze and thaw cycles and wetting and drying cycles. Volume expansion is caused by temperature changes which are dangerous for concrete durability. This test was performed as per ASTM C88-99 and it was found that all the aggregate specimens were sound enough as their values were in the permissible range of ASTM (Table-2)

3.5. Aggregate Crushing Value

This test was performed as per BS 812: Part 110. Following are the permissible limits according to the specifications of IS: 2386:

Concrete Works = 45%
Pavement wearing surfaces = 30 %

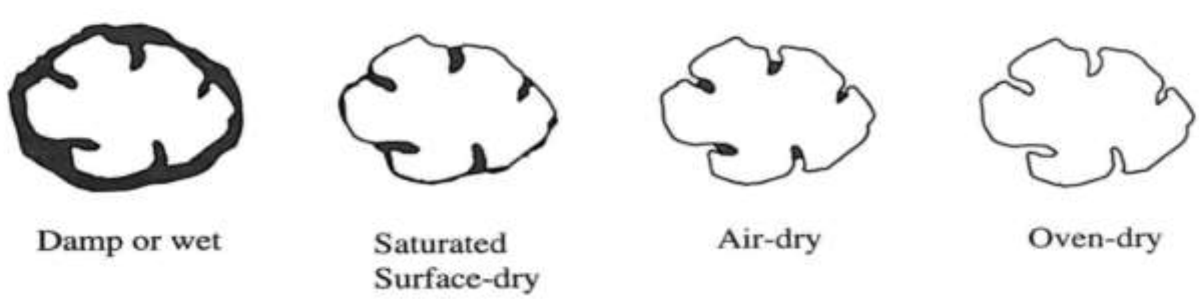


Fig. 2. Picture showing aggregates wetness and dryness conditions (ACI Education Bulletin-07-Aggregates for Concrete)

The results showed that the aggregate crushing values for specimens from Palodheri and Jamal Garhi are above 30 % and hence it is not advisable to use it on wearing surfaces but can be used in other concrete works while the samples from other localities can be safely used for both concrete and pavement. (Table-2)

3.6. Aggregate Impact Value

This test is performed using BS 812: Part 112. Following are the permissible limits according to specifications of BS 882:1992:

For heavy duty concrete floorings = 25%
For all other concrete works = 45%
For concrete used in wearing surfaces = 30%

According to the criteria mentioned in BS 882 the aggregates of Palodheri and Jamal Garhi are not suitable for heavy duty concrete floorings and as rigid pavements. However, they can be used in ordinary concrete works. (Table-2)

3.7. Loss Angeles Abrasion Value

ASTM C131 was used to perform this test. The acceptable range of abrasion is up to 50% for use in concrete (ASTM C 131 and AASHTO T 96), however, the indicated limits may vary according to the kind of application. It is observed that the abrasion value of samples from Palodheri and Jamal Garhi is greater than 30 % (Table-2).

3.8. Compressive Strength

The compressive strength of the aggregates ranges from 10,000 to 40,000 psi and the tensile strength of the aggregate varies between 300 to 2300 psi (Haq, 2012). There is little variation in the values of compressive strength of all the concrete cylinder samples (Table-2). The cylinders were casted according to specification and were cured for 28 days and the strength was determined on 28th day. The casting ratio of cylinders was 1:2:4 and w/c ratio was 0.48. The other details are appended in the table 2. Most of the cylinders failed because of the mortar but few aggregate particles were also found broken.

Table 2. Mix proportions for concrete cylinder test showing breakdown of aggregate sizes.

Constituents	**Breakdown of weight (lb)**	**Total (lb)**
Cement	4.2	4.2
Coarse aggregate range 3/4 in to 1/2 in 1/2 in to 3/8 in 3/8 in to 3/16 in	 8.8 4 4	16.8
Fine aggregate, Mixed sand FM=2.30 Sieve # 8 Sieve # 16 Sieve # 30 Sieve # 50	 3.4 2 2 1	8.4
Water	2.06	2.06

3.9. Alkali Silica Reaction

Under certain moisture conditions a chemical reaction is initiated between the alkalis present in the cement (potassium or sodium oxide) and certain siliceous minerals present in aggregate forming a alkali silica gel which causes expansion/swelling due to absorption of water and produces cracking in concrete:

$$\text{Silica + Alkali} \longrightarrow \text{alkali silica gel}$$
$$\text{Gel + water} \longrightarrow \text{expansion}$$

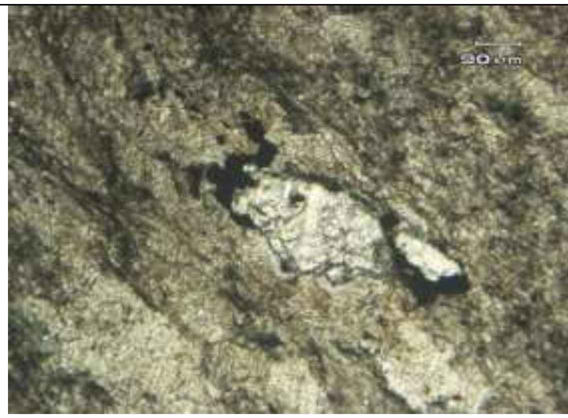
ASTM C 289, method was adopted for the determination of alkali silica reactivity and according to that the aggregates of Sawaldher, Palodheri and Maneri were found deleterious. However, the aggregates of the rest of the quarries were found innocuous.

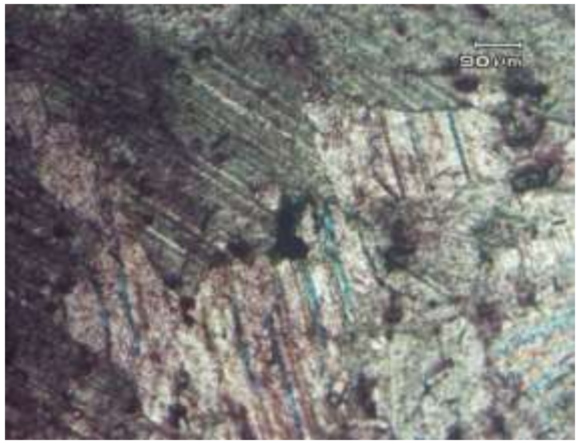
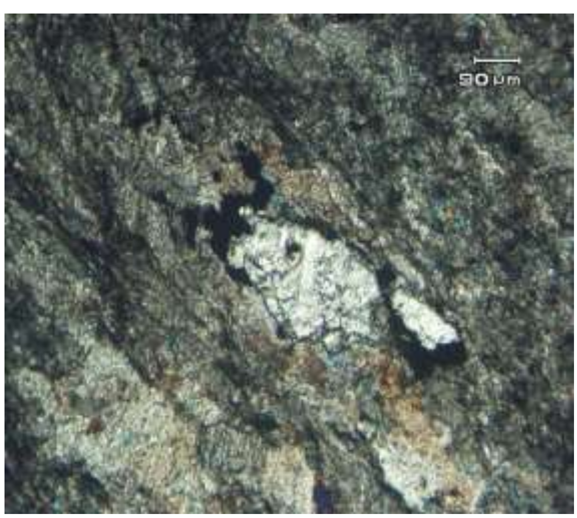
3.10. Petrographic Examination

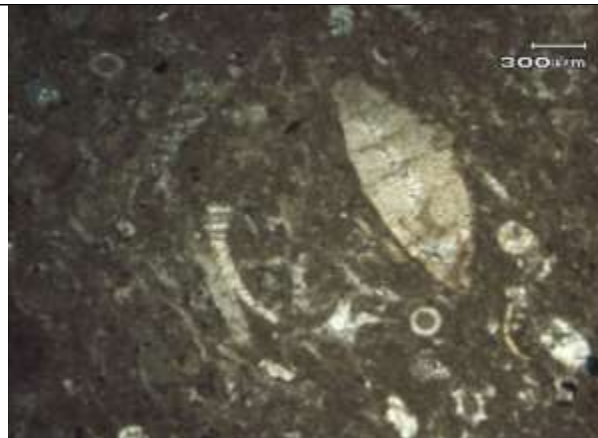
Petrographic examination is specified in ASTM C 295. The petrography of the samples determined that the samples of Palodheri and Maneri contain deleterious material.

The petrographic results of all the test samples are discussed below in Table 3.

Table 3: Petrography of the samples from different queries

Quarry	Thin Sections	Rock description
Sawaldher		Calcite = 80%, Black ore = 17%, Quartz = 03% Fine grained carbonate rock. The sample has very few microfractures which are filled with black ore. Quartz mostly occurs as granular grains in veins. Rock : Limestone Cross light
Palodheri		Carbonates = 65% Quartz = 30% Black Ore = 05% The rock shows alternate layers of fine to medium grained quartz and calcite. It seems that half of the quartz is stressed one that may cause alkali silica reaction. Since the rock has stressed quartz which may be so it seems not suitable for the use as aggregates for concrete. Rock: Siliceous Limestone Cross light
Shamozai		Calcite = 70%, Quartz = 7% Dolomite = 3%, Black ore = 20% and Mica = traces Medium to fine-grained carbonate rock. Micrite occurs as groundmass and some sparite occurs in veins or coarse aggregate grains. Black ore is found disseminated throughout the rock. Mica occurs as small grains of biotite in trace amounts. No harmful material is found in thin section. Rock: Limestone Plane light

Jamal Garhi		Carbonates = 98% Quartz = 01% Black Ore = 01% This sample is composed of recrystallized calcite grains. 90% of calcite is recrystallized while the rest occurs as micritic ground mass. No harmful material is found in thin section Rock: Marble Cross light
Palai		Carbonates 45% Quartz = 50% Black Ore = 05 % Fine to medium-grained rock. Micrite occurs in the groundmass. Quartz (Q) occurs as aggregates and also as independent grains within the groundmass. Rock: Siliceous carbonate Cross light
Maneri		Dolomite = 93%, Black Ore = traces Quartz = 7% Fine grained rock. Dolomite occurs as micritic groundmass. The rock has very few microfractures filled with black ore. Quartz occurs mostly as ghost fossil-fillings. Almost all the quartz is cryptocrystalline, occurring in aggregates. Rock: Dolomite Cross light

Margalla		Calcite= 65% Brown Ore = 05% Silica 30 % Fine grained fossiliferous rock. Groundmass is micritic containing fossils. Most of the fossils are replaced by very fine siliceous matter. Brown ore occurs disseminated throughout the rock. Rock: Fossiliferous Limestone Plane light

Quarries	Water Absorption (%)	FI (%)	EI (%)	Sound-ness (%)	ACV (%)	AIV (%)	LAA (%)	Petrography	ASR	Compressive Strength (psi)
Sawaldher	0.4	25.9	18.2	2.2	25.4	17.8	23.9	Innocuous	Delete-rious	4210.7
Palodheri	0.45	22.5	15	4.4	30.1	29.2	37.5	Deleterious	Deleterious	4149.7
Shamozai	0.47	16.3	13.4	2.7	23.5	18.2	24.6	Innocuous	Innoc-uous	4151.7
Jamal Garhi	2	16.8	32.1	7.5	31.9	29.1	38.2	Innocuous	Innoc-uous	4171.7
Palai	0.3	14.9	13.1	1.3	22.5	16.3	16.5	Innocuous	Innoc-uous	4383.7
Maneri	0.6	15.1	14.5	1.1	25.0	22.1	18.9	Deleterious	Deleterious	4376.7
Margalla	0.6	14.1	13	1.4	22.3	14.5	17.6	Innocuous	Innoc-uous	4429.3

Notes: EI=Elongation Index, FI= Flakiness Index, ACV= Aggregate Compression Value, AIV=Aggregate Impact Value, LAA=|Loss Angeles Abrasion and ASR=Alkai Silica Reactivity.

The present study shows that there are some localities in the district of Mardan that have good resource of coarse aggregate material and which can be used as an alternate source of Margalla limestone. The crush from Palai location is of good quality because different tests conducted on these samples showed that these crush samples meet the standards of ASTM (American Society of Testing Materials) or BS (British Standards). Next to Palai in quality comes the crush from Shamozai area which also has good physical and chemical properties, thus qualifying the crush for use in aggregate. Whereas the crush of Maneri showed very good physical results but failed the chemical test. The crush from other areas like Palodhri, Sawaldher and Jamal Garhi failed either in physical tests or the chemical ones.

4. Conclusions

The following conclusions are drawn from the present investigations:

- The study showed that Palai Crush qualifies the international standards and hence can be used as an alternate of Margalla. Although the Maneri aggregate failed to qualify the chemical tests but it showed very good results in physical and mechanical tests. The concrete prepared form this material may deteriorate if it comes in contact with substantial quantity of water after construction.
- The samples from Palodheri and Jamal Garhi do not qualify for concrete use on the bases of physical and engineering tests and Palodheri have not qualified even the chemical tests i.e. ASR.
- The aggregates of Shamozai showed satisfactory results.
- The aggregates of Sawaldher quarry like that of Maneri area's showed satisfactory results in physical tests but failed to fulfil the criteria in chemical tests so these may be used where there is less chance of coming in contact with substantial amounts of water.

5. Recommendations

Following are the recommendations made on the basis of results concluded from the present study:

- Palai deposit is strongly recommended for use in any type of concrete works and highways.
- Shamozai crush may be safely used in ordinary roads and concrete works.
- Palodheri and Jamal Garhi aggregates are not suitable for construction purposes.
- The aggregates of Maneri showed good results in physical test so it can be used in ordinary construction but as the chemical results are not satisfactory so it can be safely used where water exposure is least expected.
- Limestone from the Sawaldher quarry may be used in concrete construction but is not suitable for use in road construction works due to its high flaky and elongation index.
- Similar research work should be carried out in other districts of KP to find more reliable aggregate sources.

Authors' Contribution

Rubina Bilqees, conducted Petrographic studies and through revision of the draft checking its format, language etc. Fareeha Malahat, conducted all the experimental work except petrography and wrote a rough draft. Amjad Naseer supervision of experimental work and of the rough draft.

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