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CONTENTS

Analysis of Moisture Susceptibility of Different Loose Coated Asphalt Mixtures

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Abstract-The durability is one of the significant properties of bituminous paving mixtures. It is shown that moisture damage is one of the primary factors affecting the durability of the mixtures. Moisture damage is basically a combined result of two mechanisms: a) Loss of adhesion between the bitumen and aggregate interface and b) Loss of cohesion in the mixture along with several other factors like the changes in binders, aggregates qualities and something else.

The aim of this study is therefore to examine the moisture sensitivity, of different combinations of five different kinds of aggregate quarries/sources and six binder types of different penetration grade and properties, and compare the performance of these combinations between four laboratory tests: Static Immersion Test, Total Water Immersion Test (TWIT) Test, Boiling TWIT Test and Rolling Bottle Test. The tests have been carried out at the Taxila Institute of Transportation Engineering (TITE) to obtain the data for loose coated bituminous paving mixtures. The results show that the combination of Margallah aggregate source and ELVALOY Polymer Modified Bitumen provides best resistance against moisture damage and Rolling Bottle Test is the best test to discriminate between different loose coated Asphalt mixtures, irrespective of time taken by the test.

Keywords-Moisture Sensitivity Tests, ELVALOY, Polymer Modified Binder, Rolling Bottle Test, Margallah.

I. INTRODUCTION

WATER is majorly influencing the physical and mechanical properties of bituminous paving mixtures in our country. In fact, moisture damage in asphalt pavements is a global concern. Moisture damage in an asphalt mixture is defined as the loss of strength, stiffness and durability due to the presence of moisture leading to adhesive failure at the binder-aggregate interface and/or cohesive failure within the binder or binder-filler mastic. [i] Moisture damage such as stripping, rutting, raveling and fatigue cracking contributes significantly to the failure in bituminous paving mixtures. Factors are various and there are still no satisfying solutions for this problem. There are two major factors that caused moisture-related problems: adhesive failure, bitumen stripping off the aggregate surface and cohesive failure which is due to the loss of mixture stiffness. Moisture-related problems do not occur without the presence of water and traffic, which provides energy to break the adhesive bonds and cause cohesive failures. Repeated freeze-thaw cycles can also accelerate the distress in the pavement.

Since the performance of Asphalt mixtures under the affect of moisture is a very complex issue, various researches have been made to simulate the moisture damage in the past years. Asphalt technologists have carried out many attempts to develop laboratory tests to distinguish between good and poor performing bituminous mixes in regard to moisture damage dating back to the 1920s and classified the tests to identify the moisture damage resistance of an asphalt mixture into two major categories: those on loose mixtures and those on compacted mixtures. [ii]

II. PROBLEM STATEMENT

Adhesion and water proofing characteristics of bitumen made it a widely used binder in roadway pavements. However, structural and functional integrity of bituminous paving mixtures, due to loss of adhesion between bitumen and aggregate surfaces and loss of cohesion of asphalt, can be easily damaged under moisture conditions. Both mechanisms generally result in a reduction of strength and/or stiffness of the mixture and, thus, its effectiveness to accommodate traffic-induced stresses and strains. Consequently, the water-damaged pavement layer is prone to stripping i.e. physical separation of the bitumen from the aggregate and permanent deformations. Thus, water damage can also lead to early failure. Therefore it is necessary to find out how to avoid water damage. Generally speaking, adhesion between bitumen and aggregate depends on the balance of bitumen, aggregate and water system.

III. AIMS AND OBJECTIVES

The aim of this study is to examine the affinity between aggregates and binders in loose coated asphalt mixtures of various combinations by varying aggregate

quarries and grades and properties of binder, by means of additives and modifiers, and compare the performance between these different combinations using following four tests: Static Immersion Test, Boiling TWIT Test, Rolling Bottle Test, TWIT Test. In order to achieve this aim, a few series of water sensitivity tests on loose coated asphalt mixtures were carried out.

IV. Literature Review

Mechanics of the bonding of aggregate-binder interface, which is highly affected due to moisture conditions, influences the response of bituminous mixtures towards different distresses. Basically following three mechanisms result in moisture degradation of an asphalt mixture i.e. a) Loss of cohesion within binder, b) Adhesion failure between binder and aggregate interface (i.e. Stripping) and c) Degradation of aggregate. In evaluation of binder's resistance against moisture damage, the critical parameter is bond strength, which is between asphalt and aggregate interface. [iii] K. Majidzadeh and F. N. Brovold [iv] carried out study to alleviate deformations or to control the rate of deteriorations in pavements, caused by the moisture damage, resulted in utilization of anti-stripping additives. The physico-chemical bond between the bitumen and aggregate in a bituminous mixture can be increased by using anti-stripping additives. These anti-stripping additives can also be used to improve the wetting of asphalt over aggregate surface by lowering the surface tension of the bitumen. The affect of hydrated lime on the mechanism that affects the adhesive bond between bitumen and aggregate in a bituminous mixture is evaluated again in 2013 [v], but this time, by using surface free energy method. The results of this surface free energy method indicated that hydrated lime increases the wettability of asphalt binder over the aggregate and improves the adhesion between the asphalt binder and aggregate. Also, the difference between surface free energies of asphalt-aggregate and water-aggregate is higher in samples made with untreated aggregates, as using hydrated lime caused these values to decrease. This implies that more energy is needed for stripping phenomena to occur, and the rate of moisture damage decreases .

In 1990, K. D. Stuart [vi] practiced following five anti-stripping additives in the laboratory (a) traditional liquid additives, (b) metal ion surfactants, (c) hydrated lime and quick lime, (d) silane coupling agents and (e) silicone. Among these five additives the most commonly used and effective solid type anti-stripping agents are Hydrated and quick lime. In 2009, C. Gorkem and B. Sengoz [vii] studied the affect of hydrated lime on the stripping potential and moisture susceptibility characteristics of hot mix asphalt (HMA). The results of which showed that the addition of hydrated lime in hot mix asphalt (HMA) increased the resistance of asphalt mixtures to the detrimental effect of moisture. Sobolev et al. [viii] studied the addition of Fly ash in asphalt pavements for the improvements in performance of asphalt binders as compared to those improvements which are achieved through polymer modification.

In 1960's and 1970's, many attempts were made by researchers for the modification of existing test procedures, for determining moisture sensitivity of asphalt mixtures, and simulation of these methods with actual field conditions. These attempts resulted in a very effective moisture sensitivity test development when Lottman's test protocol was introduced in industry. This achievement is considered as breakthrough in the history of moisture sensitivity tests development and standardized under the AASHTO test procedures specifications T283. Texas freezethaw pedestal test and Texas boiling test were also introduced to industry at that time [ix].

V. Methodology

Four tests were performed to carry out the study of moisture susceptibility of loose coated asphalt mixture comprises of different grades and different properties of asphalt binders (by application of additives and modifiers) i.e. Static Immersion Test, Total Water Immersion Test, Boiling Water Test and Rolling Bottle Test. The commonly used grades are 10/20, 60/70 and 80/100, the binders with additives are Lime additive 60/70pen binder and Fly Ash additive 60/70pen binder, and Polymer Modified Binder (PMB) comprises of ELVALOY (DuPont reactive ethylene tarpolymer).

TABLE I
Mean Penetration Values of Selected Binders

Sr. No	Binder Type	Mean Penetration Value(mm)
1	10/20 pen	14
2	60/70 pen	61
3	80/100 pen	84
4	Lime Additive 60/70 pen	53
5	Fly Ash Additive 60/70 pen	26
6	Polymer Modified Binder	24

The aggregates from Rohi, Ubban Shah, Margallah, Sargodha and Garrhi Habib Ullah were used in these combinations along with binders mentioned above. The results so obtained are compared between moisture resistant properties for, different grades, additives and modifiers of different binders, aggregate properties and four moisture sensitivity tests mentioned earlier.

The methodology adapted for this work is shown in Fig. 1.

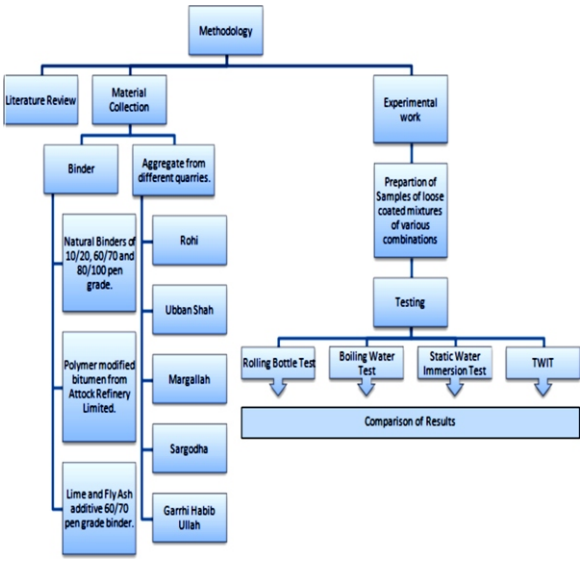

Fig. 1. Research Methodology

VI. Results and Discussion

A. Static Immersion Test

The observation of this test is only to estimate the percentage of the total visible area of the aggregate which remains coated as above or below 95 percent. It was found that the stripping of the binder is not very obvious, and what is more, most of the results are nearly 100% remained. The results are plotted on Fig. 2.

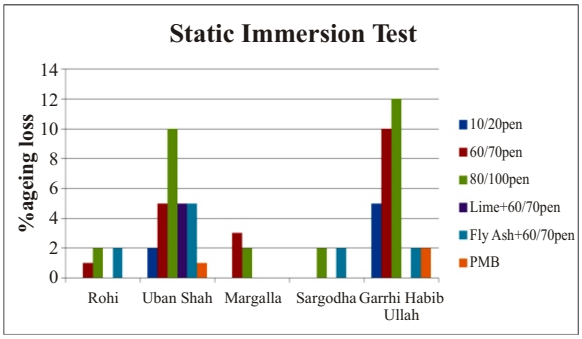

Fig. 2. Results for Static Immersion Test

From the bar chart, we can see that most combinations show good bonding properties except for the combinations of Garrhi Habib Ullah and Ubban Shah with 80/100pen binder and also of Garrhi Habib Ullah with 60/70pen binder, which are 12% and 10% stripping of binder, respectively. The combination of Ubban Shah with 60/70pen simple and along with Lime and Fly Ash as additives and Garrhi Habib Ullah along with Fly Ash additive binder also lost 5% of binder.

B. Rolling Bottle Test

In the Rolling Bottle Method, the degree of bitumen coverage of the particles is checked after 6 hours, 24 hours, 48 hours, and 72 hours. The bar chart below shows the total loss of bitumen after 72 hours.

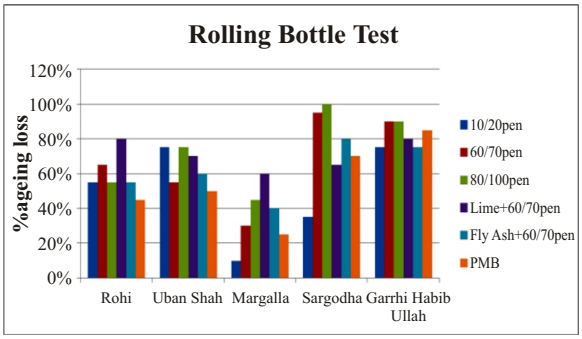

Fig. 3. Percentage loss of Bitumen after 72 hours of Rolling Bottle Method

It can be seen from the bar chart clearly that 80/100pen, 60/70pen and Lime additive 60/70pen binder had the highest binder lost after 72 hours. The loss of Fly Ash additive 60/70pen binder, however, is just slightly less than above mentioned binders. However, Polymer modified binder shows very better bonding properties. In terms of aggregate, Margallah performs better than other sources. To be specific Garrhi Habib Ullah has the worst bonding properties, followed by Ubban Shah and Sargodha, while Margllah is the best which is only about 25-30% average binder loss. As far as the comparison of 6 and 24 hours of 60/70pen binder with Lime additive 60/70pen binder is concerned, a very distinct and clear decrease in percentage of binder loss is observed.

C. Total Water Immersion Test

TWIT assesses the average percentage of binder coverage after immersion in 40°C water after 3 hours. This test is improved from Static Immersion Test. It uses 40°C water rather than room temperature (25°C) to provide a better result. As present before, the results of Static Immersion Test are not obvious; however, Figure below shows the results of Total Water Immersion Test which are comparatively clearer. From the bar chart we can see that Rohi and Margallah have very little binder loss compared with Ubban Shah and Garrhi Habib Ullah. The percentages of binder loss for these two are all less than 5% for the three binder types. When it comes to Ubban Shah and Garrhi Habib Ullah, the percentages of binder loss are quite higher. However, Sargodha shows nearly the same bonding properties with Margallah which are only 4% for Lime additive 60/70pen binder and no binder loss for 10/20pen and Polymer Modified binder. Ubban Shah is again the worst aggregate with 25 to 30% binder loss, followed by Garrhi Habib Ullah, which have 10% and 25% binder loss. 10/20pen and Polymer Modified

binder have very good bonding properties when compared with other binders.

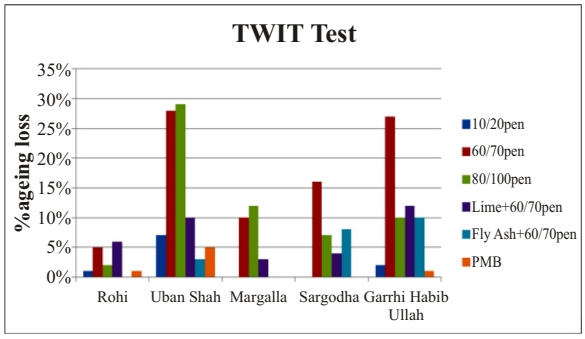

Fig. 4. Results of TWIT

D. Boiling Water Test

The Boiling Water Test estimates the percentage of bitumen coverage after 10mins boiling. The results are very obvious.

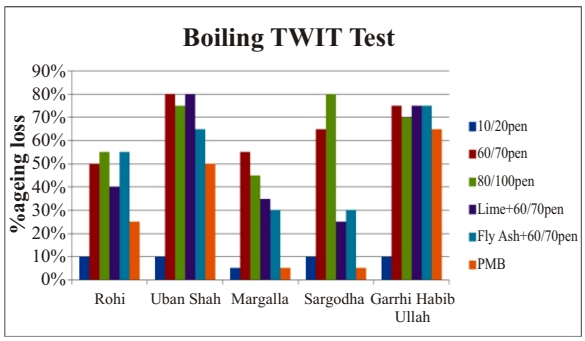

Fig.5. Results of Boiling Water Test

Fig. 5 shows the percentage of binder loss for Boiling Water Test. From the bar chart, we can see that Ubban Shah and Garrhi Habib Ullah, again, have the worst bonding property. As for Margallah and Sargodha, the bond property with Lime additive 60/70pen binder is almost equal (Margallah and Sargodha) or better (Sargodha) than that with Fly Ash additive 60/70pen binder. In terms of Ubban Shah, Margallah and Garrhi Habib Ullah, 80/100pen binder seems to have a better bond property than 60/70pen binder except for Rohi and Sargodha which has 5-15% more binder loss. Since 80/100pen is softer than 60/70pen binder, the bonding property of it should be worse. However this result is different from the expected outcome. The reason why this happened may because that 80/100pen has a lower softening point and when boiling the sample the 80/100pen binder began to flow like large pieces around the aggregate particles and when boiling stopped , the binder start to subside on the aggregate surface. Moreover there is half an hour cooling time, many binder pieces may subside on the particles. More tests should be done to support this supposition. Bar chart also shows that the bonding behavior of PMB is far better than other binders against boiling also. However, in case of Margallah and Sargodha aggregate sources coated with PMB, only 5% binder loss is observed.

VII. Results Analysis

A. Aggregate Source

The results indicate that Margallah has a better bonding property followed by Rohi. Generally speaking, hydrophobic aggregates are less sensitive to moisture, i.e. are more resistant against stripping, than hydrophilic aggregates. As hydrophobic aggregates forms a better bond therefore it is hard for water to access to the surface of aggregates. Hence it can form bonds with the bitumen film more easily leading to less possibility of stripping. Iron, magnesium, calcium and perhaps aluminum are considered beneficial, while sodium and potassium are considered detrimental. Limestone, i.e. Margallah and Rohi, is defined as a rock of sedimentary origin composed principally of calcium carbonate or the double carbonate of calcium and magnesium, or a combination of these two minerals. Therefore it should have a better bonding property which is proved by the results.

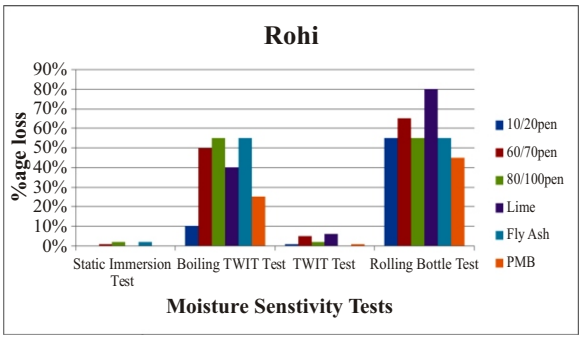

Fig. 6. Moisture Sensitivity Test Results for Rohi

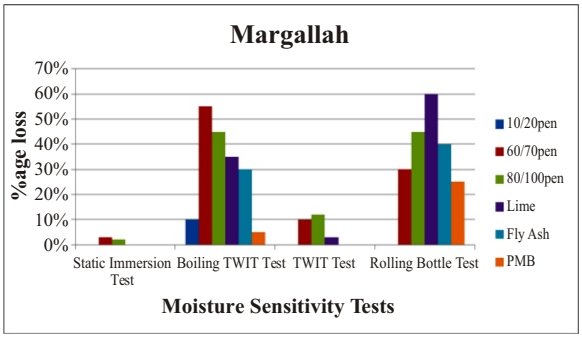

Fig. 7. Moisture Sensitivity Test Results for Margallah

Both the two types of Margallah source i.e. Rohi and Margallah crush have quite low water sensitivity. Mostly results are less than and up to 50-55% of binder loss. The Static Immersion Test and Total Water Immersion Test are not suitable to distinguish the

difference between these two aggregates. There are some minor differences in TWIT which can make a distinction between these two aggregate quarries. Boiling TWIT and Rolling Bottle Test can provide a better reference in related to their bonding properties. Based on the results Margallah have the best bonding properties in both 10/20 pen and Polymer Modified binder types, while Margallah bonds well also with Fly Ash additive 60/70pen binder. Rohi has showed more water sensitivity to the Lime additive 60/70 pen binder and virgin 60/70, 80/100 binder types and same in the case of aggregates from Margallah quarry.

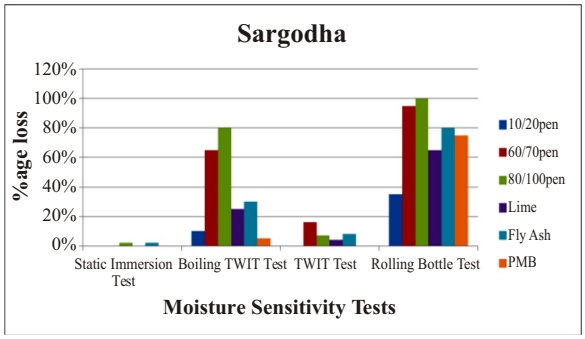

Fig. 8. Moisture Sensitivity Test Results for Sargodha

Aggregates from Sargodha quarry indicated relatively better results. Again Static Water Immersion Test and Total Water Immersion test have not shown clear results whereas other two showed the percentage loss of binder very clearly. Sargodha has shown less binder loss with the binders having additives and modifications as compared to the virgin binders. Results indicate better bonding of Sargodha aggregates with Polymer Modified Bitumen followed by the Lime additive Binder

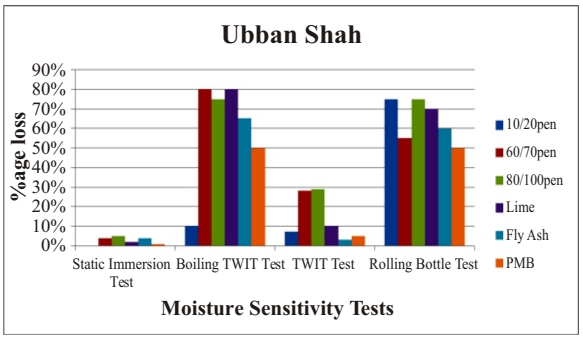

Fig. 9. Moisture Sensitivity Test Results for Ubban Shah

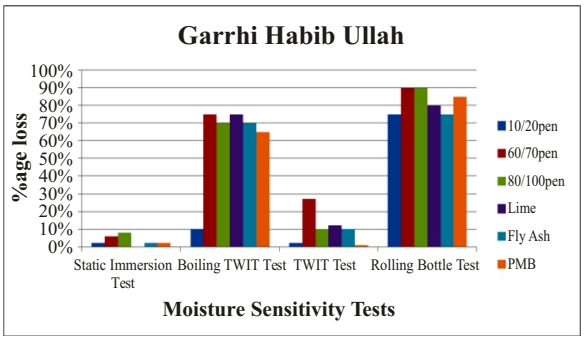

Fig. 10. Moisture Sensitivity Test Results for Garrhi Habib Ullah

Remaining two types of aggregates i.e. Ubban Shah and Garrhi Habib Ullah have very high moisture sensitivity. The percentages of binder loss are all very high especially with the Rolling Bottle Test and Boiling TWIT Test. Almost all the tests can be used to distinguish the difference between these two, Ubban Shah and Garrhi Habib Ullah, aggregate sources. Boiling TWIT Test and Rolling Bottle Test (regardless the testing time) are the best tests to make a distinction between them. TWIT Test can also provide a very reasonable reference to distinguish these aggregate types. In addition, Static Immersion Test is also slightly suitable this time.

Based on the results shown above, both Ubban Shah and Garrhi Habib Ullah aggregate sources have better bonding properties with both 10/20pen and Polymer Modified binder types which is relatively slight weaker than limestone based Margallah and Rohi aggregates, and has the reasonable water sensitivity to the binder type. The sensitivity to the 60/70 binder type is quite strange for Ubban Shah and Garrhi Habib Ullah, however in general, soften binder has a weak bonding property, but in these two cases 80/100pen binder bonds well than 60/70pen Binder in Boiling TWIT Test. The reason for this may because the droplets of binder subside on the aggregate surface with no adhesion or cohesion and this percentage of binder coverage is also counted. Above all, Garrhi Habib Ullah is the worst aggregate type with very high moisture sensitivity, followed by Ubban Shah.

B. Effect of Binder

Adhesive forces between bitumen and aggregate in asphalt mixtures are directly affected by the consistency of bitumen, sensitivity for temperature and other indicators and thus the strength of asphalt pavement and asphalt pavement performance is affected. The higher viscous asphalt has better resistance against moisture than the lower viscous asphalt due to the more polar substances and good wet-ability. 10/20, 60/70 and 80/100pen binder are normal natural Virgin binders and Lime and Fly Ash additive binder made by 60/70pen binder (35% by weight of binder). The Polymer Modified binder is modified

from 60/70pen binder by adding ELVALOY (DuPont reactive ethylene tar polymer).

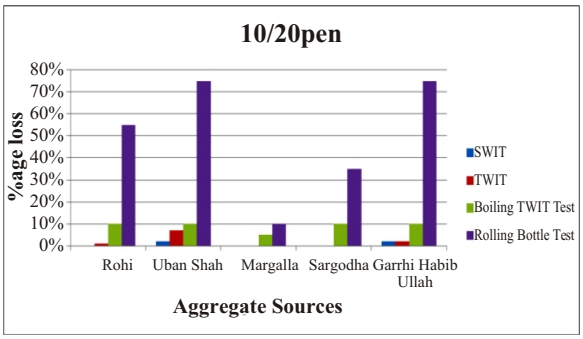

Fig. 11. Moisture Sensitivity Test Results for 10/20 pen Binder

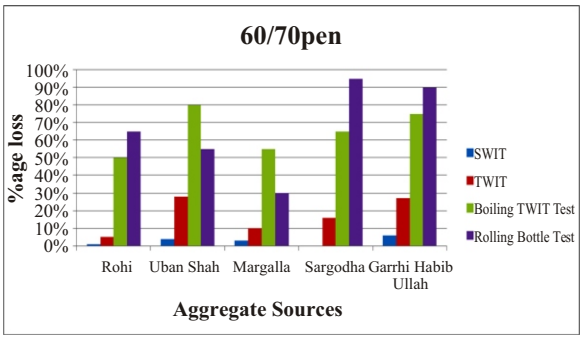

Fig. 12. Moisture Sensitivity Test Results for 60/70 pen Binder

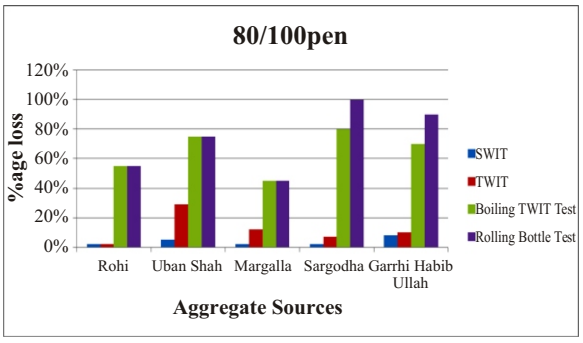

Fig. 12. Moisture Sensitivity Test Results for 80/100 pen Binder

Generally speaking, higher the viscosity of binder higher will be the resistance against moisture damage therefore, the 10/20pen binder is far better and has shown very less percentage loss of binder over aggregate surface. From remaining types of binder, 60/70pen binder is better than 80/100pen binder, because it is stiffer and the penetration of it is much smaller than 80/100pen binder and the softening point is higher. However, the percentage of binder loss of all aggregate types is still comparatively very high, which is hardly acceptable in the field. Therefore anti-stripping additive should be used if the virgin binder needs to be used in the field. The anti-stripping additives (Lime and Fly Ash) and the Polymer Modified binder are therefore tested.

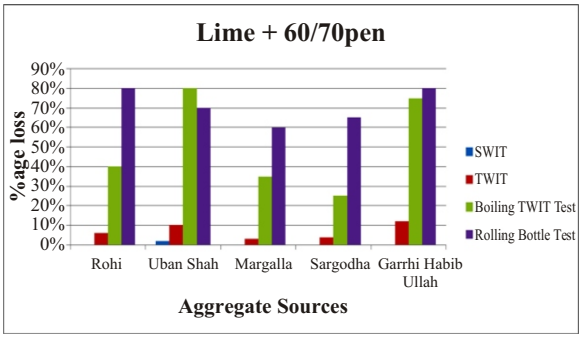

Fig. 13. Moisture Sensitivity Test Results for Lime Additive 60/70 pen Binder

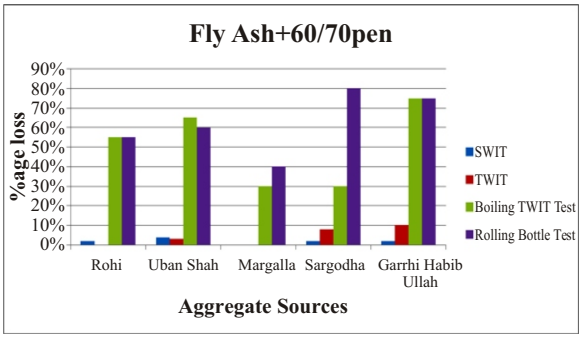

Fig. 14. Moisture Sensitivity Test Results for Fly Ash Additive 60/70 pen Binder

Lime and Fly ash are well known and widely used anti-stripping agents. Most anti-stripping agents reduce surface tension between the bitumen and aggregate in a mixture. When surface tension is reduced, increased adhesion of the bitumen to the aggregate is promoted. Thus, most liquid anti-stripping agents are surface-active agents.

From the bar charts above, we can see that the total percentage of binder loss using Fly Ash additive binder is reduced when compared with Lime additive 60/70pen binder for both Margallah (40%) and Rohi (55%). The better anti-stripping additive for Margallah is Fly Ash with only 30% binder lost as compared to Lime with only 5% better than natural 60/70pen binder. For Sargodha, Ubban Shah and Garrhi Habib Ullah both the Lime and Fly Ash additive binder have shown almost equal percentages of binder loss.

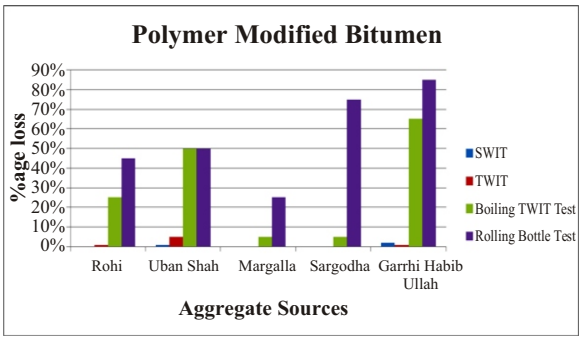

Fig. 15. Moisture Sensitivity Test Results for Polymer Modified Binder

Modification techniques highly affect the performance of asphalt mixtures and are more desirable as compared to the mixtures which are modified with anti-stripping additives. Therefore, Polymer Modified Bitumen should have better bonding properties as compared to Anti-stripping additive binders, which is shown in the results. From the bar charts, we can see that the total percentage loss of binder from the aggregate surface is decreased dramatically by using PMB especially in case of Margallah and Rohi which showed only 25% and 45% binder loss respectively in Rolling Bottle Test where as in Boiling TWIT Test, the percentage of binder loss is reduced to just 5% with Margallah. The worst results of PMB are with Garrhi Habib Ullah aggregate source with up to 85% binder loss followed by the Sargodha aggregates with 75% binder loss in Rolling Bottle Test. Ubban shah also shows almost 50% binder loss with Polymer Modified Bitumen.

One thing must be noticed here that the Boiling TWIT Test showed relatively less percentage of binder loss in case of Polymer Modified Bitumen with all types of aggregate source, which means that ELVALOY (DuPont reactive ethylene tarpolymer) has more resistance against heating affect. It showed only 5% loss with Margallah and Sargodha. As a whole, Polymer Modified Bitumen showed good bonding with almost all types of aggregates regardless of test type.

VIII. Conclusions

Regardless of testing time, Rolling Bottle Test is the most reasonable and acceptable test to evaluate the moisture sensitivity. Meanwhile, Boiling Water Test is the most effective test with the least testing time. TWIT can make a distinction between Limestone based Margallah & Rohi, and others that are Sargodha & Ubban Shah. But as for Static Immersion Test, it is only suitable for Ubban Shah and Garrhi Habib Ullah mixtures, which have very poor bonding properties.

The aggregate characteristics do affect the moisture sensitivity to some extent, irrespective of which type or grade of bitumen is used. The results indicate that Margallah and Rohi have better moisture resistance than remaining types of aggregates. To be specific, Margallah presents the best bonding property while Ubban Shah and Garrhi Habib Ullah show the worst bonding property. That means aggregates containing alkali metals like sodium and potassium exhibit relatively high moisture sensitivity, while aggregates containing calcium, magnesium and iron show little indications of moisture sensitivity. Consequently decreasing the contents of alkali metals in aggregate is a contributor to prevent moisture damage.

Polymers and additives can improve the adhesion between binder and aggregate significantly. To be specific, Polymer Modified binder is the best among all the binders by improving the total percentage of binder loss of Ubban Shah for Boiling TWIT from 80% to 50% and of Margallah from 55% to only 5%. Apart from Polymer Modified Binder, even though Fly Ash additive binder is not polymer based modified binder, it is the better modified binder for Margallah by improving the total percentage of binder loss from 55% to 30%. On the contrary, Garrhi Habib Ullah is only 15% better than the results obtained with virgin binder.

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Simulation of Daily Rainfall Through Markov Chain Modeling

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Abstract-Being an agricultural country, the inhabitants of dry land in cultivated areas mainly rely on the daily rainfall for watering their fields. A stochastic model based on first order Markov Chain was developed to simulate daily rainfall data for Multan, D. I. Khan, Nawabshah, Chilas and Barkhan for the period 1981-2010. Transitional probability matrices of first order Markov Chain was utilized to generate the daily rainfall occurrence while gamma distribution was used to generate the daily rainfall amount. In order to achieve the parametric values of mentioned cities, method of moments is used to estimate the shape and scale parameters which lead to synthetic sequence generation as per gamma distribution. In this study, unconditional and conditional probabilities of wet and dry days in sum with means and standard deviations are considered as the essential parameters for the simulated stochastic generation of daily rainfalls. It has been found that the computerized synthetic rainfall series concurred pretty well with the actual observed rainfall series.

Keywords-Markov Chain, Daily Rainfall Occurrence, Daily Rainfall Amount, Gamma Distribution

I. INTRODUCTION

Daily rainfall is one of the most vital meteorological parameter for agriculture based economy like Pakistan, as the majority of the populace is straightforwardly or circuitously fastened with the horticulture and associated products [i]. Agricultural productivity is positively or negatively affected due to the availability, unavailability or excessive overflow of water through Indus water network that is vulnerable to daily rainfalls [ii-iii]; mainly in monsoon season [iv-v]. Hence, sufficient and in time rainfalls are not only beneficial to the Kharif but also favorable and advantageous to the upcoming Rabi crops [vi].

Cutting-edge techniques of statistics ameliorated the applied methods' area available for the data analysis especially which are not normally distributed. This progression is of significant importance, as daily rainfalls are evidently not normally distributed [vii-viii]. In the contemporary epoch, the advancements for the developing models of daily rainfall frequency are significantly improved. Furthermore, besides the data generation, it renders the valuable information in agriculture, aviation and in many other related hydrological applications. Hence, an appropriate diurnal rainfall frequency model, in particular the probabilistic distribution of wet and dry spells, is substantial [ix].

Being a random phenomenon of rainfall occurrence, Markov Chain is generally considered as an effective illustration of the rainfall frequency. Then again, amount of daily rainfall is also crucial in weather characteristics, in particular, for agriculture. Both, the occurrence and amount of rainfall are also interconnected to the temperature, humidity and solar radiation as well as soil water balance that are also eminent in respect of growth and then further development of agricultural products, pests and related diseases, and, the weeds control. Because of this reason, in several agro-climatic studies, analysis and associated modeling of rainfall is chiefly focused, in which availability of the archives containing the record of rainfall data is very important.

In the field of consecutive rainfall frequencies, [x] are considered as the pioneers. They fitted the first order Markov Chain model to Tel Aviv data in successful manner. Lately, [xi] found that the same order is compatible for fitting the daily rainfall occurrence over Italy. The base of Markov Chain model is the assumption that occurrence of daily rainfall depends on the previous day's condition (i.e. whether it was dry or wet). It is considered as one of the most challenging problem in the field of hydrometeorology because extreme events like floods and droughts have been also in a relationship and driven by the daily rainfall. Hence, it is not easy task to model the daily rainfall stochastically because of its highly varied inherent nature [xii].

In general, sufficiently long time series of daily rainfall is utilized as input in hydro-meteorological models. In addition, to evaluate the sensitivity and suitability of such models, ensemble datasets are required to assess the long term changes in the rainfall regime. Then, the observed sequence provided a weather process realization that further used as an input data rainfall time series, in detailed impact studies from the simulated scenarios of climate change. Though, numbers of these sequences are still small in range because of the high computational cost of such

scenarios. As a consequence, a synthetic sequence of rainfall data, based on the stochastic structure of the process is needed to evaluate the different ranges of outcomes that may be obtained with other equivalent series. This method was adopted by [xiii] to simulate the rainfall data, temperature and solar radiation on daily basis. First order Markov Chain has been utilized for the daily rainfall to describe the precipitation frequency while to approximate the distribution of the amount, exponential distribution has been employed. Afterward, [xiv-xv] replaces the exponential distribution by gamma distribution which has been now commonly adapted for most of the climate change studies.

Dry and wet behavior of weather is of great significance to all directly related and allied fields like agriculture, livestock, hydrology, industry, etc. The appropriate model of daily rainfall may be utilized in agricultural planning, drought management, flood predictions and soil erosion, climate change studies, and some other associated fields. The objective of the study is to develop a Markov Chain model for rainfall occurrence. Moreover, modeling of daily rainfall amount has been made which is desirable for wet days.

II. Materials and Methods

A. Study Area

For the study, five different meteorological stations selected from each of the province i.e. Multan, D. I. Khan, Nawabshah, Barkhan and Chilas from Punjab, Khyber Pakhtunkhwa, Sindh, Balochistan and Gilgit-Baltistan administration, respectively (Fig. 1).

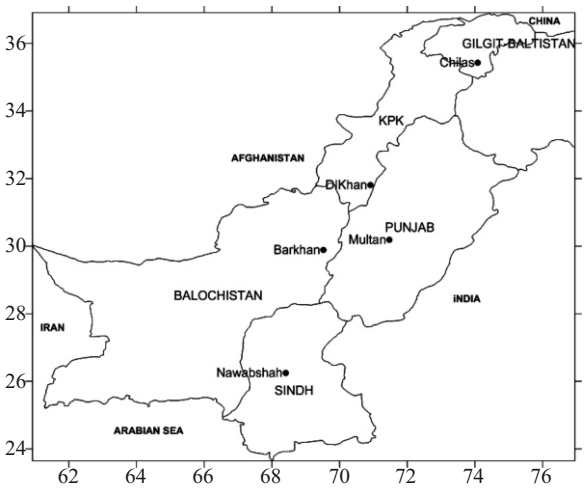


Fig. 1. Map showing the locations of selected cities of Pakistan

Daily rainfall data of 30 years (i.e. 1981-2010) utilized in the study is obtained from the archives of Pakistan Meteorological Department (PMD). The standard SI unit of millimeter (mm) is used in the study. For the studied period, highest and lowest amount of total normal rainfall is found for Barkhan (405.62mm) and Nawabshah (144.3mm), respectively. D. I. Khan bore the highest value of extreme rainfall (150mm) as on 4th August, 2010 while least extreme value is observed over Barkhan (104.2mm) for 23rd August, 1984. Fig. 2 shows the parametric values for all the considered cities of the country.

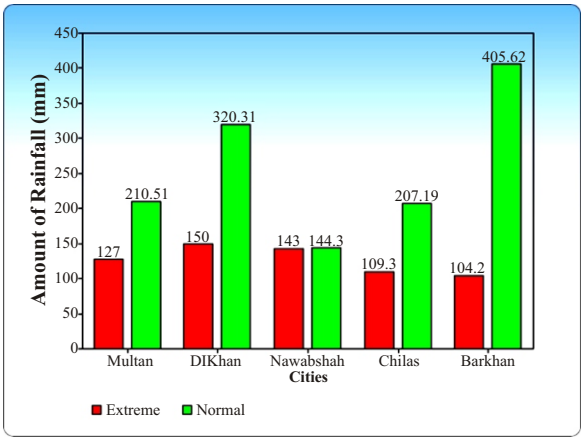


Fig. 2. Normal and extreme rainfalls for the period of 1981-2010

B. The Rainfall Model

a) Rainfall Probability

For the recorded *n* years, if specific event occurred in *m* of these years, subsequently probability of that occurred event in any given year is *m/n*. [xvi] illustrated that a curve may be fitted to the probabilities should be transformed to assure that the fitted curve is one of the probabilities given by

$$F = log(\frac{p}{1-p}) \quad (1)$$

Where $p = 0\ to\ 1$

If *t* is the day of the year then function F(*t*) may be fitted to the *f* values and thus fitted probabilities may be given by

$$p(t) = exp\ \{\frac{F(t)}{1+exp\ F(t)}\} \quad (2)$$

Fourier series for the function F(*t*) of *n* harmonics is

$$F(t) = a_o + a_1 sinx + b_1 cosx + a_2 sin2x + b_2 cos2x + \ldots a_n sinnx + b_n cosnx \quad (3)$$

Where $x = \frac{\pi t}{366}$

A function given by this expression joins at the beginning and end of the year. This provides the curve with 2*n*+1 coefficient that describe the rainfall pattern here.

b) Rainfall occurrence

Occurrence of Rainfall may be described by two state Markov Chain model i.e. either day is dry or wet. Hence chance of rain or not on a particular day depends on the previous day that whether rain occurred or not. This kind of probabilistic approach based on Markov Chains has been utilized in many studies [xvii-xix] to generate synthetic rainfall sequence.

If random variables *X0, X1, X2, ..., Xn,* are identically distributed by considering only two probabilities, i.e. 0 and 1 such that

Xn = 0 *or* 1 if the nth day is wet or dry, respectively.

Initially, it may be assumed that,

$$P(Xn+1 = Xn+1 | Xn = xn, Xn-1 = xn-1, \dots, Xo = xo) = P(Xn+1 = xn+1 | Xn = xn) \quad (4)$$

Where $xo, x1, \dots, xn+1 \epsilon \{0,1\}$

Thus, it is expected that chance of rainy day depends only on the previous day (i.e. was wet or dry). In this assumption the probability of wetness is independent of further preceding days, therefore, the stochastic process $\{X_n\}$ with $n = 0,1,2, \dots$ is a Markov Chain [xx].

Comparatively simple model concern with the probabilities of weather conditions depends on the state of preceding day, can be a simple transition matrix as

$$\begin{bmatrix} p_{oo} & p_{01} \\ p_{1o} & p_{11} \end{bmatrix}$$

On condition that $p_{ij} = p(X_1 = j | X_0 = i)$ $i,j = 0, 1$ is the probability, if a given day is type of *i* then it will be followed by a day of type *j*, that is p_{01} is the conditional probability of rainy day following a dry one, while p_{11} is the conditional probability of a rainy day following a wet one and so on in case of p_{10} and p_{00}.

Chance of the wet day occurrence may be ascertained by the comparison of a random number generated from a uniform distribution between the numerical values of 0 and 1 to the values of the mentioned transition probabilities p_{01} and p_{11}. If the random number is not larger than p_{01} than current day is wet and the preceding day was dry and the decision process is similar in case if the preceding day was wet. In this manner, once the wet day occurrence is established, the amount of rainfall on that is determined by generating a new random number from a uniform distribution and by solving the inverse cumulative function for the daily rainfalls.

c) Rainfall Amount

Amount of rainfall during rainy days can also be modeled to get the mean rainfall(s) per rain day. It not only set the desired variable for fitting of the amounts but also estimates the shape parameter of the utilized gamma distribution, then

$$F(x) = \frac{(k/\mu)x^{k-1}e^{kx/\mu}}{\Gamma(k)} \quad (5)$$

Where Γ is the gamma function, depends on the two parameters i.e. shape parameter *k* and the scale parameter μ i.e. mean rainfall per day which is assumed to be constant throughout the year and was estimated from all rainfall amounts. Consequently, with the implication of this condition, four curves were fitted to the mean amount of rain per rain day.

III. Results and Discussion

The process of Markov Chain represents a system of components making transition from one state to another over time. The technique used in the study involves the utilization of first order transition probability matrix of a Marko Chain in addition to an algorithm to produce the time series of daily rainfall values. The way in which Markov Chain model can be utilized to generate rainfall time series have been illustrated in the subsequent sections.

A. Probability of Rainfall

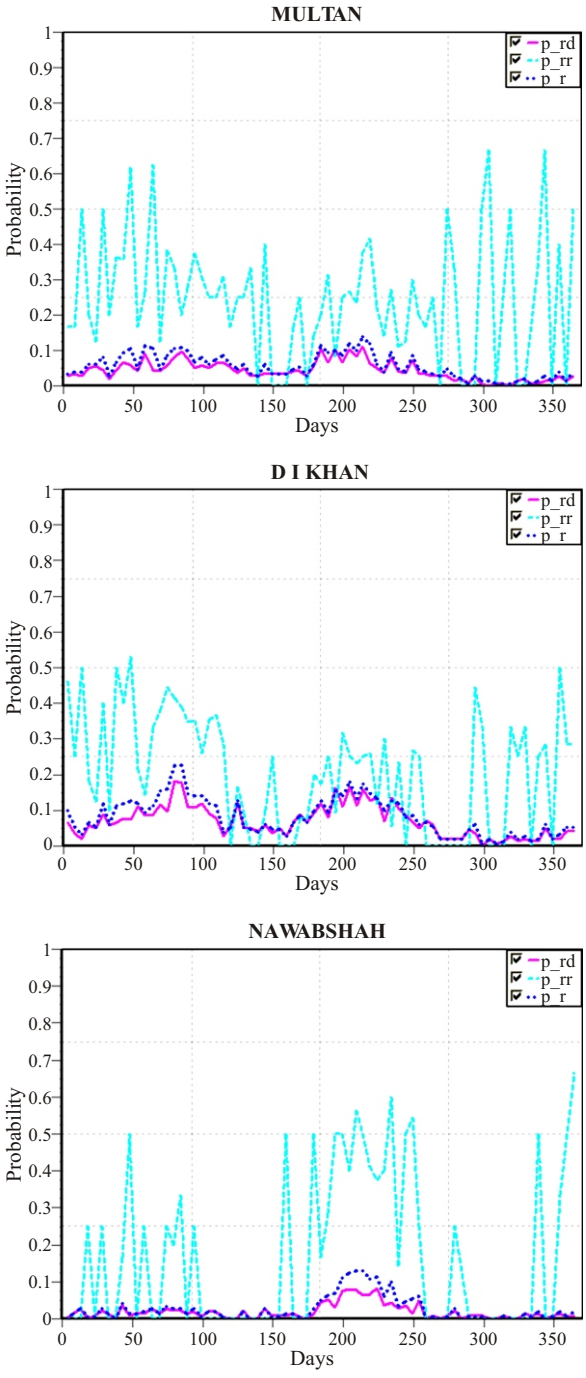
Rainfall probability is a helpful computational tool to study and analyze the distribution of rainfall in time. Several studies, as for instance, [xxi-xxiii] presented that rainfall occurrence probability at specific time is dependent on the preceding day(s) condition, called conditional probability. Contrariwise, independent rainfall occurrence is an unconditional probability (or overall probability) of rainfall.

B. Conditional and Unconditional Probability

At given place on any given date(s), the proportion of wet days estimated the overall rain probability as (p_r). For the reason that it explore the overall chance of rain in the main (summer monsoon season) and small (winter) rainy season, at that place, such information is meaningful for agricultural planning. The analysis of first order Markov Chain deals with the computational probabilities of rains that depends on the condition whether previous day was rainy (p_rr) or dry (p_rd).

The conditional and unconditional probabilities of daily rainfall for the considered cities are depicted in Fig. 3. Chance of getting rain on a particular day in the small rainy season shows a significant continual increase for all the cities, if followed by a wet day. On the other hand, the probability of getting rain in the small rainy season will decrease significantly, if flowed by a dry day. Hence, the condition explores that the chance of rain occurrence in the small rainy season is significantly depended on whether the previous day was wet or dry. In D. I. Khan and Chilas small rainy season (with amplitude differences) appears with prominent values of probability. While Nawabshah,

Barkhan and Multan shows the prominent large season's probabilities. Nawabshah appears with the least values of rr and rd. The D. I. Khan and Chilas appears with dominant small value probabilities as this area is more affected during the western disturbances era rather than eastern summer monsoon times [xxiv]. Also there is a very little demarcation of small and large season for Chilas.



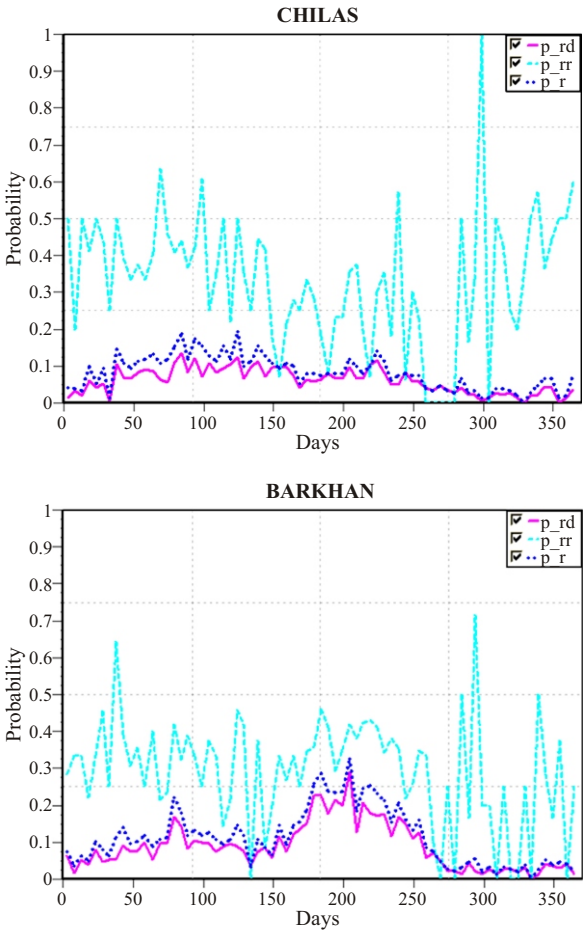


Fig. 3. Overall (p_r) and conditional probabilities (p_rr & p_rd) for the different cities of Pakistan

C. Fitting the probabilities

To observe the smooth and clear state of the rain probability, fitting of the probabilities to the chance of rain with the previous days, whether dry or wet, is performed. Variation in between the treatment implies response variation which is '*explained*' by the factor (i.e. predictor variable) in the model, and its sum of squares summarizes the model variability predictions (the fitted values). Variation within each factor level is '*unexplained*' by the factor in the model and its sum of squares (also called residual sum of squares) construe that how much the response values vary around best prediction of the response for that factor level. Total sum of squares reflects the overall variability of the response via

$$SS_{Total} = SS_{Explained} + SS_{Unexplained} \quad (6)$$

which may be expressed in the form

$$\sum(y_{ij} - \bar{y})^2 = \sum(fit_i - \bar{y})^2 + \sum(y_{ij} - fit_i)^2 \quad (7)$$

Where y_{ij} is the '*raw*' response after assuming randomized data with a categorical factor satisfying a normal model of the form

$$y_{ij}=(explained\ by\ factor)\ +\ (unexplained) \quad (8)$$

or

$$y_{ij} = \mu_i + \varepsilon_{ij} \quad (9)$$

For $i = 1\ to\ g$ and $j = 1$ to n_i where $\varepsilon_{ij} \sim$ normal $(0, \sigma)$

and fitted values for categorical, linear and quadratic models, respectively are given by

$$fit_i = \begin{cases} \bar{y}_i \\ b_o + b_1 x_i \\ b_o + b_1 x_i \quad b_2 x_{i^2} \end{cases} \quad (10)$$

Obviously each sum of squares is associated with a particular degree of freedom, as under

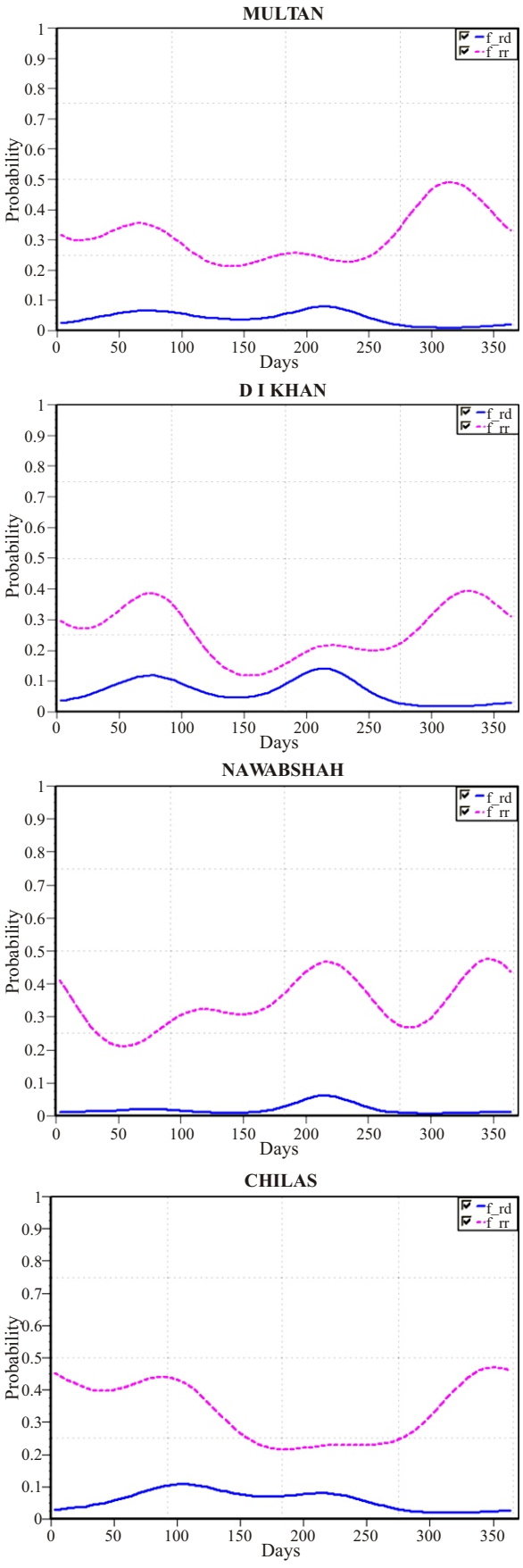
$$\begin{aligned} df_{total} &= n - 1 \\ df_{residual} &= n - k \\ df_{explained} &= k - 1 \end{aligned} \quad (11)$$

implies that sums of squares are found by dividing each sum of squares by its degrees of freedom. Then *F* ratios are simply calculated by dividing each mean '*explained*' sum of squares by the mean residual sum of squares

$$F = \frac{MSS_{explained}}{MSS_{Unexplained}} \quad (12)$$

If the added parameter(s) have no effect, the corresponding F ratio is expected to be around 1, though it can be somewhat higher or lower by chance. A p-value assesses whether it is unusually high and is interpreted in a similar way to all other *p*-values -- the closer the *p*-value to zero, the stronger the evidence that the term is needed in the model.

Hence, this results in the fitted probabilities (f_rd & f_rr) for the mentioned cities are drawn as shown in Fig. 4. For D. I. Khan, Nawabshah, Chilas and Barkhan over all probability of rain after a rainy day is less than 50% while for Multan, probability in small rainy season of a rainy day after the previous wet day reaches almost up to 50% to be occurring. For D. I. Khan and Chilas, and, for Multan and Nawabshah, chance of rain after a dry day is less than 10% and 20%, respectively.



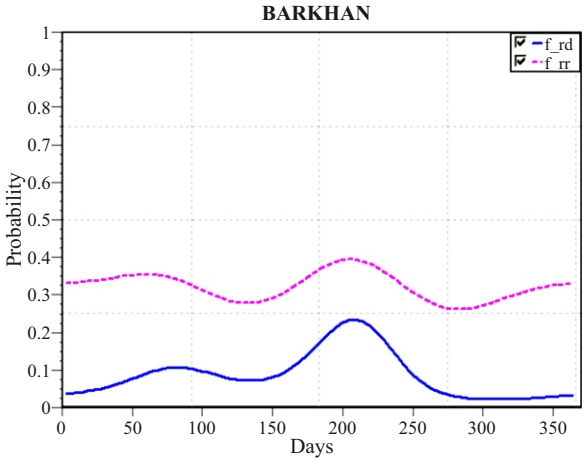
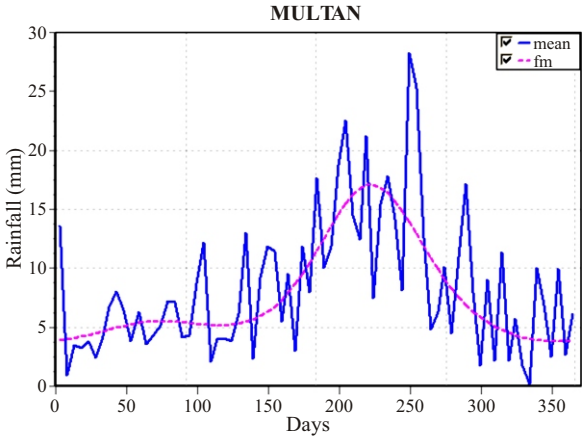
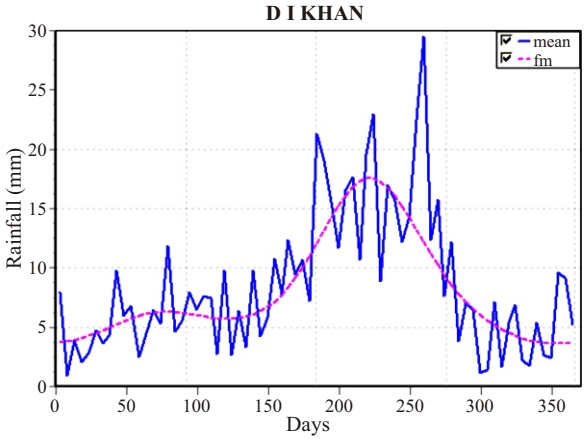


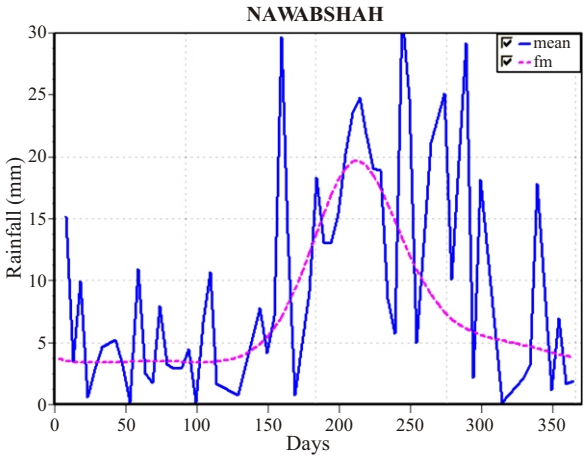
Fig. 4. Fitted means to the conditional probabilities for different cities of Pakistan

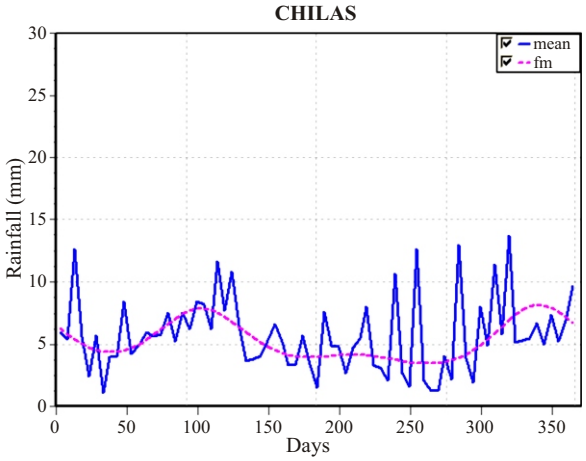
D. Modelling of Rainfall Amount

Gamma distribution is used to described the amount of rainfall. This distribution comprises of two parameters, scale parameter i.e. mean rain per day (μ) and shape parameter of the distribution (k). The mean rain per rain day (μ) is computed and after repeating the fitting process for rainfall amounts, plotted in Fig. 5. The fitted curves shows that mean rain per rain day vary in time and acquire maximum values in the peak months of large season with larger values in Multan and D. I. Khan (≈17mm), Nawabshah (≈20 mm), and Barkhan (≈12 mm) as these stations are more influenced in monsoon season rather than westerlies while rainfall amount of Chilas is greater in small rainy season.









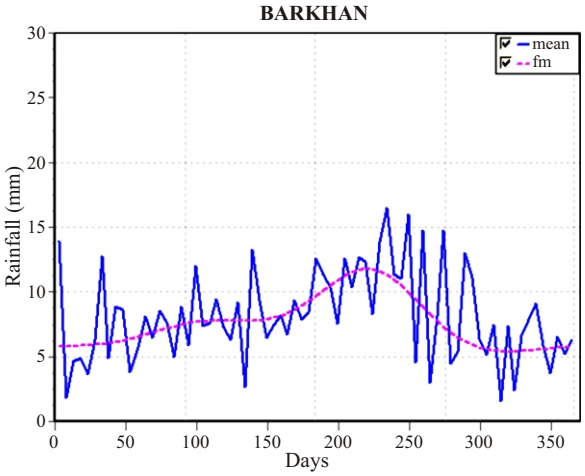


Fig. 5. Overall mean and fitted mean of rainfall amounts for different cities of Pakistan

Through the method of maximum likelihood, k-value for the each city is estimated that is assumed to be constant throughout the year. The calculated shape values have close values for the considered cities though, D. I. Khan (≈0.79) and Multan (≈0.72) appears with maximum and minimum, respectively (Fig. 6). Higher values of the shape parameter show analogous to exponential behavior of rainfall in the considered cities.

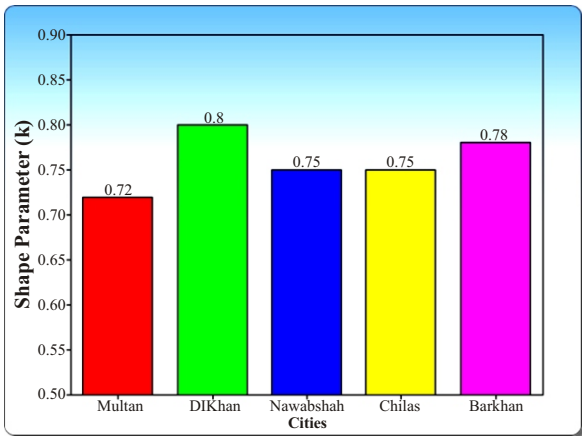
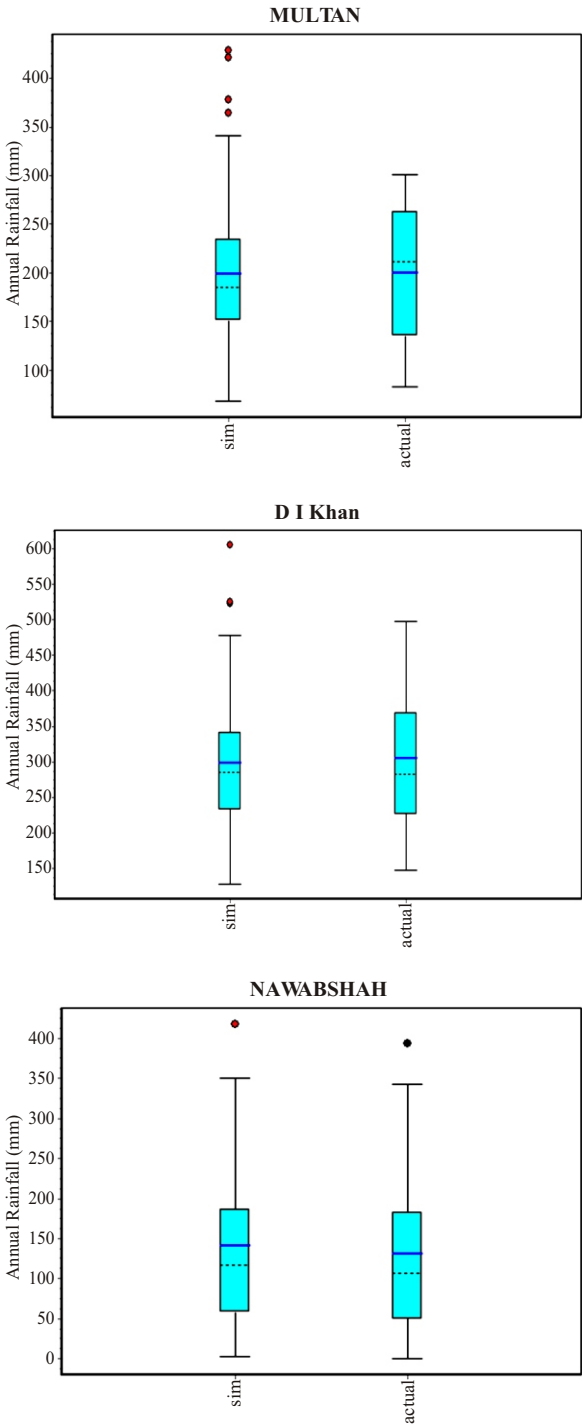


Fig. 6. Annual shape parameter for the respective cities

IV. Validation of the Model

In addition to the recognized procedure illustrated above, the synthetic rainfall time series were examined thoroughly to uncover their ability to uphold the statistical properties and to evaluate the applicability of Markov Chain models for rainfall generation. In this milieu, the significant statistical parameters are the general parameters (i.e. mean, standard deviation, etc.), autocorrelation functions and the probability distribution of the time series.



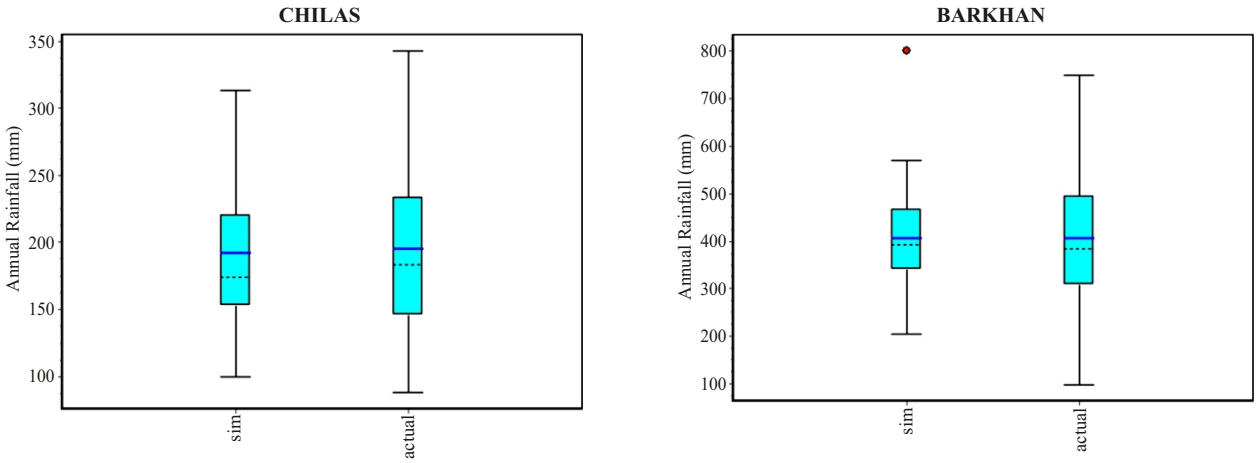


Fig. 7. Actual and simulated rainfall by first order Markov model for different cities of Pakistan

In order to examine the accuracy of first order Markov Chain modeling approach, the general statistical parametric values such as mean, standard deviation and the percentiles of the simulated values are summarized in Table I. Keeping in view the highly varied nature daily rainfalls, the comparison shows that the simulated values by the first order Markov Chain model is sufficient to preserve most of the nature of actual data, which implies the adequacy of the fitted Markov Chain model in respect of daily rainfalls for the selected cities of Pakistan.

TABLE I
SOME CHARACTERIZED STATISTICAL AND ANALYTICAL VALUES FOR SIMULATED AND ACTUAL DATA

City		Mean	Std. Deviation	20th percentile	50th percentile	80th percentile	Min	Max
Multan	Simulated	198.54	75.78	134.32	184.8	264.14	67.831	428.81
	Actual	202.97	71.66	126.14	212.3	287	83	300.7
D I Khan	Simulated	297.7	89.24	222.34	285.73	358.46	127.76	605.09
	Actual	305.27	100.24	216.7	282.1	416.4	147.3	497
Nawabshah	Simulated	141	99.6	49.9	116.4	212	2.6	417.8
	Actual	130.2	110.1	29.6	107.3	242.3	0	393.4
Chilas	Simulated	191.9	58.8	148.3	173.8	253.2	99.6	313.7
	Actual	194.7	69.5	137.8	183.2	250.1	88.1	342.8
Barkhan	Simulated	406.1	101.6	331.3	392.2	476.8	204.7	800.9
	Actual	405.6	160.4	290.3	385.0	510.8	98.1	749.5

V. CONCLUSIONS

The models have utilized 30 years actual rainfalls to simulate the 50 years of synthetic rainfall time series. This study has examined the relative efficiency of the use of rainfall amount and wet days in the determination of generated rainfall at five different cities (Multan, Chitral, Nawabshah, Chilas and Barkhan) of Pakistan. Outcomes of this work show that both methods (the use of rainfall amount and wet days) are equally efficient with respect to the mean rainfall and wet days. The total predicted number of wet days is based on a first-order Markov Chain process for the month and the total amount of monthly rainfall for wet days is determined by gamma distribution. The total normal rainfall over Barkhan and Nawabshah are found to be of the highest (405.62mm) and lowest (144.3 mm) amount, respectively. D. I. Khan bears the highest extreme value (150 mm) while the least extreme appears for Barkhan (104mm) which is very close to Chilas extreme (i.e. 109.3mm). For D. I. Khan and Chilas small rainy seasons are dominated for the probability of rainfall while chance of rainfall in Multan is found up to 50% in the season if the previous day was also rainy. Fitted means exhibit the same scheme in a clearer and smooth way. An overall probability of rainy day after wet day is much greater than the rainy day followed by a dry one. Fitted mean of

rainfall amount disclose the value under 10 mm for D. I. Khan and Chilas throughout the year. In respect of Barkhan these values are not below the 6 mm. It has been noted that simulated rainfall time series agreed fairly well with the actual observed rainfall series.

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A Novel Approach for the Reuse of the Textile Bleaching Wastewater

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Abstract-In this paper, the efficiency of used hydrogen peroxide (H_2O_2) bleach bath was assessed for the elimination of hydrolyzed unfixed reactive dyes from cellulosic fabrics. The aim of this study was to reuse textile wastewater and develop a new textile dyeing and wash-off method with small quantities of water and chemicals, without compromising quality of dyeing. For this purpose, spent bleach bath having H_2O_2 was collected from a textile industry and used in wash-off step of fabric after dyeing with reactive dyes to determine colour fastness properties and shade strength of selected reactive dyes. Five dyeings were carried out, using C. I. Reactive Yellow 138, C. I. Reactive Orange 122, C. I. Reactive Red 195, C. I. Reactive Blue 221, and C. I. Reactive Black 5 and dyed samples were passed through both conventional wash-off and new wash-off method containing spent bleach bath. Washing fastness, rubbing fastness, change of colour, and magnitude of total colour difference (ΔE*) values of both washed-off fabrics were compared. The colourfastness properties and final shade of fabrics washed-off with spent bleach were found to be comparable to those washed-off conventionally. This study concludes that spent bleach bath containing H_2O_2 is a potential nominee for the removal of hydrolyzed reactive dyes from cotton fabrics.

Keywords-Bleaching, Textile Dyeing, Wash-off, H_2O_2, Wastewater, Colour Fastness

I. INTRODUCTION

Textile industry is one of the most polluting sectors of Pakistan accounting the amount of fresh water used during the operations of industry and amount of wastewater discharged after the operation [i-ii]. Major environmental problems of textile sector are related to this water consumption and discharge [iii-iv]. Cellulosic fibres are most commonly dye with reactive dyes because of their high colour fastness and ease to apply [v-vii]. These dyes have strong affinity with cotton because their reactive groups make covalent bond with cotton [viii]. Still these dyes have high affinity with water, so fixation reaction is stalled by dye hydrolysis leaving unfixed dyes [v], [vii], [ix-x]. The reactions of reactive dye are shown in Fig. 1.

These hydrolyzed dyes are necessary to remove from dyed material to obtain acceptable colour fastness properties and shade strength. Wash-off process is carried out for the removal of all the excess/unfixed dyes and other chemicals used in the dyeing process. Conventional wash-off method is carried out in many steps at high liquor ratio including hot and cold wash, soaping agents and acid. Thus this step is highly water demanding process of textile industry [xi-xii]. In the past, textile wastewater has been reused in dyeing and finishing after biological treatment, and treatments based on ultrafiltration and membrane technologies [xiii-xiv]. Furthermore, several researchers have tried to reduce water consumption in washing process by developing special washing detergents, cationic fixing compounds, and easy-to-wash dyestuffs [xi], [xv-xvi].

In this novel research effectiveness of used bleach bath having hydrogen peroxide (H_2O_2)in wash-off as washing agent to remove unfixed dyes from material was accessed. In industry bleaching of cotton is widely achieved by using H_2O_2 as bleaching agent [xvii]. H_2O_2 dissociate at high pH (10-12), forming per hydroxyl anions (HO^-_2) refer to (1) which is responsible for bleaching action [xviii].

$$H_2O_2 \rightleftharpoons H^+ + HO^-_2 \qquad (1)$$

The results achieved in the present study propose that conventional wash-off method can be replaced by spent bleach bath as washing agent without compromising colour fastness and colour strength. By this novel method water and energy consumption and pollution load will be reduced.

II. MATERIALS & METHOD

2.1 Materials

In this study, 100% cellulosicknitted fabric of single jersey construction and 200 g/m^{2}weight was used. Five reactive dyes used in the study are given in Table I. Chemicals used for dyeing like sodium chloride (NaCl) and sodium carbonate (Na_2CO_3),were of commercial grade and used without any further purification.

2.2 Methods

2.2.1 Dyeing and washing

All dyeing was carried out with 5% o.w.f (on weight of the fibre) of dyes to obtain dark shades. In all trials fabric of 20g divided into four swatches, each of 5g weight was used.The dyeing was carried out in an IR (infra red) laboratory dyeing machine (Datacolour, Ahiba Nuance) at a liquor ratio of 1:8, in the presence of 80 g/L NaCl and 20 g/L Na_2CO_3.

All samples were dyed at 60ºC for 60 minutes according to isothermal all-in-one laboratory method. After dyeing samples were taken out from dyeing machine, rinsed in tap water and exposed to wash-off treatment. One swatch of fabric from each dyeing sample was washed-off with conventional methods shown in Table II. This swatch was treated as reference sample.

TABLE II
CONVENTIONAL WASH-OFF METHOD

Step	Washing Steps	Temp. (ºC)	Time (min)
1	Cold rinse	30	10
2	Neutralization with CH_3COOH	30	10
3	Warm Wash	50	10
4	Hot Wash	80	10
5	Soaping	85	10
6	Cold rinse	30	10

The remaining three swatches of fabric were subjected to new wash-off method consisted of 1 to 3 washing stepsusing 100% spent H_2O_2 bleach bath, as shown in Table III. First, second, and third fabric swatches underwent washing step 3, steps 3-4, and steps 3-5, respectively. After the completion of wash-off process, samples were removed from the machine, squeezed, dried, and conditioned for 24 hours before evaluation ofthe uniformity of dyeing, change of shade and colour fastness properties.

TABLE III
NEW WASH-OFF METHOD USING SPENT H_2O_2 BLEACH BATH

Step	Washing Steps	Temp. (ºC)	Time (min)
1	Cold rinse	30	10
2	Neutralization with CH_3COOH	30	10
3	Wash#1 with spent H_2O_2 bleach	50	10
4	Wash#2 with spent H_2O_2 bleach	80	10
5	Wash#3 with spent H_2O_2 bleach	85	10
6	Cold rinse	30	10

2.2.2 Colour measurement and fastness properties

The colour fastness of sample fabrics was evaluated using AATCC test methods. AATCC test methods 61-2001-2A and 8-2001 were used to assess colour staining and rubbing fastness respectively [xix], [xx]. Colour difference values between samples washed-off with conventional and new methods were determined using a spectrophotometer (Data colour, Spectra flash SF-600 Plus CT) at the following settings: CIELAB colour equation, Illuminant D65, specular reflection included mode, 10º Standard observer, and aperture size of LAV 30 mm [vi]. After folding each sample twice, four measurements were carried out at different positions on the fabric surface and averaged.

III. RESULTS AND DISCUSSION

To determine the fastness properties of samples after treating them with the used bleach, they were subjected to different number (1 to 3) of treatments. Table IV shows a comparison of fastness properties of reference and samples washed-off using used H_2O_2 bleach water. Similar washing and rubbing fastness was observed in the data after used H_2O_2 bleach wash-off. This data was collected on the basis of multi-fiber staining. For C. I. Reactive Yellow 138dyeing, the fabric sample washed-off with spent H_2O_2 bleach water showed identical fastness properties, mainly in the range of 4.5 to 5.0 as shown in Fig. 2. The change of shade was found to be 4.5, showing a similar shade compared to that of reference. In case of C. I. Reactive Red 195, the good fastness values confirm that new wash-off method under investigation is effective in removal of all hydrolyzed dyes. Similar trend is followed by all other dyes.

ΔL^* (difference in lightness), Δc^* (change in chroma), Δh^* (change in hue), and ΔE^* *(total colour difference)*values (Table V) are used for the account of colour differences between reference fabric and those washed-off using spent H_2O_2 bleach water. Negligible colour difference is observed in all cases i.e. $\Delta E^* < 1.1$.The results apposite to C. I. Reactive Yellow 138demonstratethat 1st wash-off using used H_2O_2 bleach water was good enough to achieve similar depth of shade. Negligible differences in lightness ($\Delta L^* = -0.48$), Hue ($\Delta H^* = -0.35$), and total difference ($\Delta E^* = 0.51$) confirm that colour properties of treated fabric were equivalent to those of the reference sample.

The total colour difference (ΔE*) was further reduced to 0.38 when sample underwent 3rd wash-off.

In the case of C. I. Reactive Red 195, the shade of sample treated with usedH_2O_2bleachwas found to be slightly darker (ΔL* = -1.12), slightly duller (Δc* = -1.12), and within tolerable total colour difference (ΔE* = 0.77). Results were not improved by further washing so it was concluded that in case of red 195 only one wash using used H_2O_2 seems to be sufficient to remove hydrolyzed dye. Values of ΔE for of C. I. orange 122 all three wash-offs were in acceptable limit (ΔE<1.1). For C. I. Reactive Blue 221 and C. I. Reactive Black 5, total colour difference (Δ*E**) values of 0.86 and 0.08 were achieved at 1st wash. These results are previously discussed in similar way [xxi].

A direct relation between the total colour difference (Δ*E**) and number of wash-off treatments is shown in Fig. 2.

IV. Conclusion

A new wash-off method was investigated in this study for the effective removal of deposited hydrolyzed dyes with reduced quantity of fresh water from the cotton fabric. The efficiency of the new method using spent H_2O_2 bleach water was investigated on cotton fabrics dyed with C. I. Reactive Yellow 138, C. I. Reactive Red 195, C. I. Reactive Blue 221, C. I. Reactive Orange 122 and C. I. Reactive Black 5indark shades. On the basis of results obtained in this study, it is concluded that similar colour fastness properties with minimal colour difference i.e, 4.5 and with reduced water consumption with respect to conventional dyeing and wash-off process, can be achieved by used H_2O_2 bleach based wash-off method. This study concludes that used H_2O_2 bleach is a potential candidate for removing the unfixed reactive dyes from cotton fabrics.

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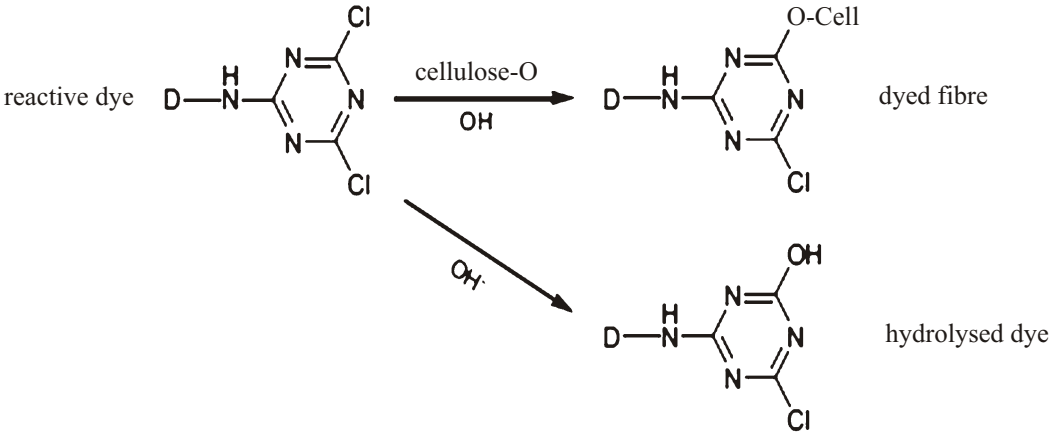


Fig. 1. Reaction of reactive dyes

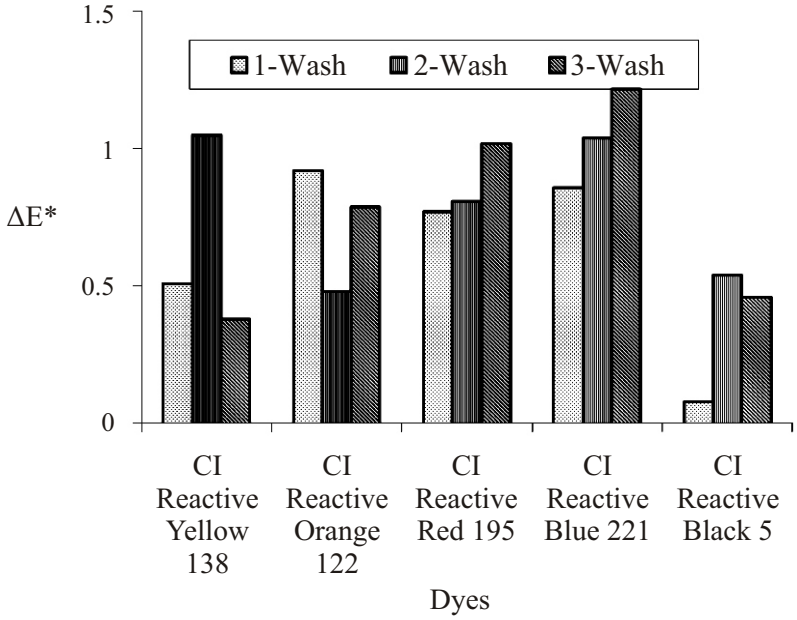


Fig. 2. Effect of washes on total colour change (ΔE*)

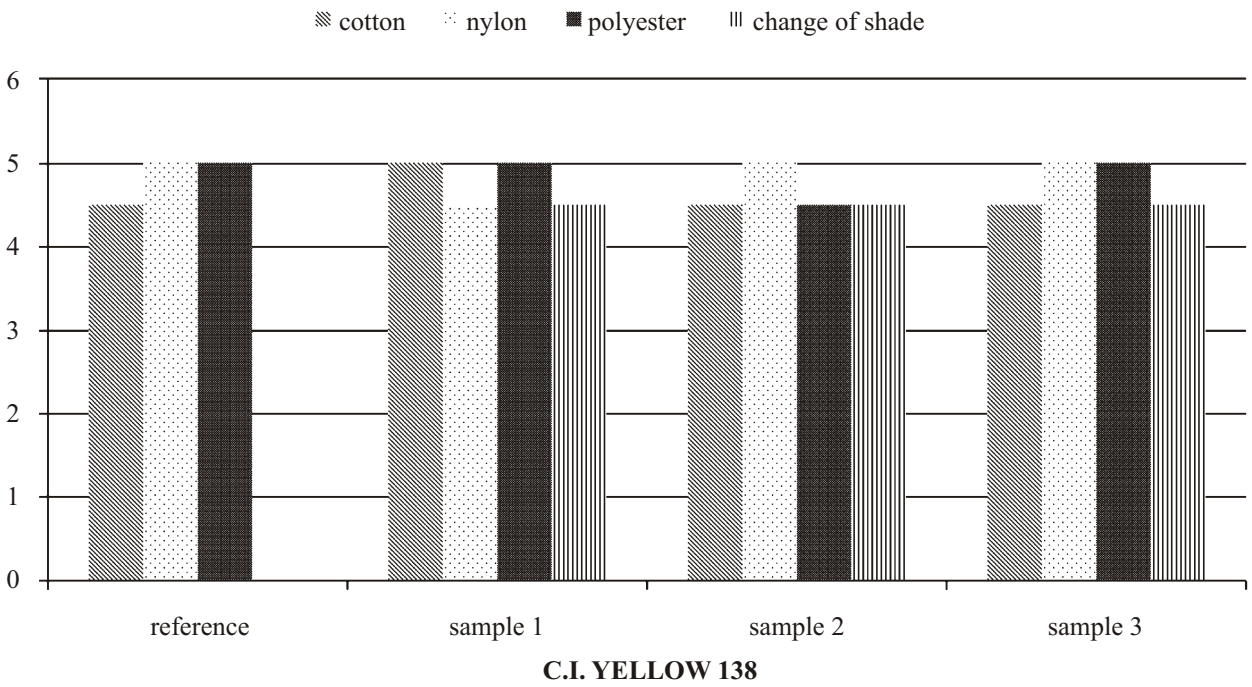


Fig. 3. Effect of reuse washes on wash fastness and change of shade

TABLE I
REACTIVE DYES USED IN THE RESEARCH

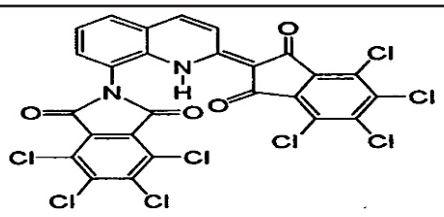
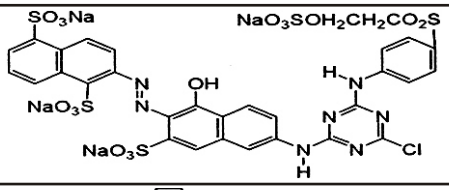
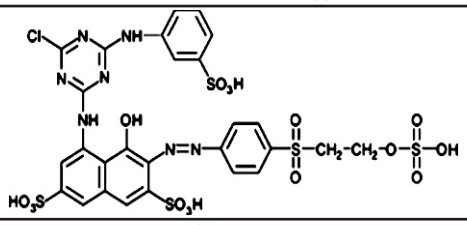
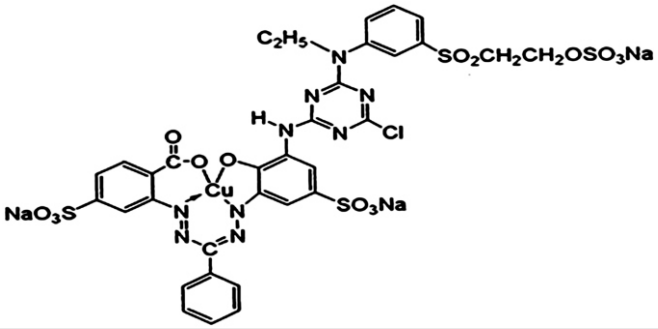
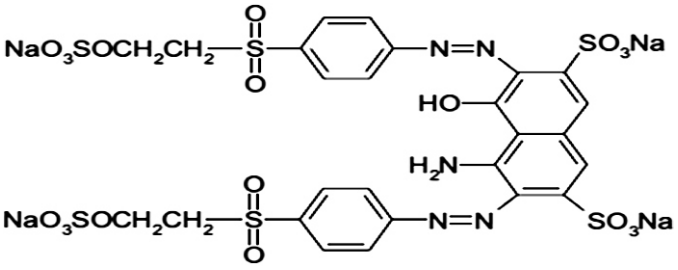
C. I. name Commercial name Molecular formula Molecular weight (g/mol)	Chemical Structure
C.I. Reactive Yellow 138 Procion Yellow H-EXL $C_{26}H_6Cl_8N_2O_4$ 693.96	
C.I. Reactive Orange 122 Jakofix Orange ME2RL $C_{31}H_20ClN_7O_{16}S_5.4Na$ 1034.25	
C.I. Reactive Red 195 Assofix Red 3BF $C_{31}H_{19}ClN_7O_{19}S_6.5Na$ 1136.32	
C.I. Reactive Blue 221 Synozol Blue K-BR $C_{33}H_{24}ClCuN_9Na_3O_{15}S_4$ 1082.83	
C.I. Reactive Black 5 Sinarcion Black VBS $C_{26}H_{21}N_5Na_4O_{19}S_6$ 91.82	

TABLE IV
COLOUR FASTNESS PROPERTIES OF SAMPLES WASHED-OFF WITH SPENT H_2O_2 BLEACH BATH

	No of Washes	Crocking		Multi-fiber staining			Change of shade
		Dry	Wet	Cotton	Nylon	Polyester	
				C.I. Reactive Yellow 138			
Reference	-	5	5	4.5	5	5	-
Sample-1	1	5	5	5	4.5	5	4.5
Sample-2	2	5	5	4.5	5	4.5	4.5
Sample-3	3	5	5	4.5	5	5	4.5
				C.I. Reactive Orange 122			
Reference	-	5	5	5	5	4.5	-
Sample-1	1	5	5	5	5	5	4.5
Sample-2	2	5	5	4.5	5	5	4.5
Sample-3	3	5	5	4.5	5	4.5	4.5
				C.I. Reactive Red 195			
Reference	-	5	5	4.5	5	5	-
Sample-1	1	5	5	4.5	4.5	5	4.5
Sample-2	2	5	5	4.5	5	4.5	4.5
Sample-3	3	5	5	4.5	4.5	5	4.5
				C.I. Reactive Blue 221			
Reference	-	5	5	5	5	5	-
Sample-1	1	5	5	5	5	4.5	4.5
Sample-2	2	5	5	4.5	4.5	5	4.5
Sample-3	3	5	5	4.5	5	5	4.5
				C.I. Reactive Black 5			
Reference	-	5	5	5	5	5	-
Sample-1	1	5	5	5	4.5	5	4.5
Sample-2	2	5	5	5	5	4.5	4.5
Sample-3	3	5	5	5	5	5	4.5

TABLE V
CIELAB COLOUR DIFFERENCES OF SAMPLES WASHED-OFF WITH SPENT H_2O_2 BLEACH BATH AND COMPARED WITH REFERNCE

Dyes	No of Washes	CIELAB Colour difference values					
		ΔL*	Δa*	Δb*	Δc*	Δh*	ΔE*cmc
C.I. Reactive Yellow 138							
Sample-1	1	-0.48	0.88	0.87	1.19	-0.35	0.51
Sample-2	2	-1.06	1.78	1.56	2.22	-0.80	1.05
Sample-3	3	-0.09	0.69	0.52	0.79	-0.35	0.38
C.I. Reactive Orange 122							
Sample-1	1	0.00	-0.62	1.06	0.39	1.16	0.92
Sample-2	2	-0.94	-0.63	-0.44	-0.75	0.18	0.48
Sample-3	3	-1.46	-0.84	-0.07	-0.60	0.58	0.79
C.I. Reactive Red 195							
Sample-1	1	-1.12	-1.10	-0.60	-1.12	-0.56	0.77
Sample-2	2	-0.67	-1.02	-1.21	-1.06	-1.17	0.81
Sample-3	3	-0.28	-1.37	-1.67	-1.41	-1.63	1.02
C.I. Reactive Blue 221							
Sample-1	1	0.39	-0.87	0.76	-0.71	-0.92	0.86
Sample-2	2	0.04	-1.08	0.97	-0.89	-1.14	1.04
Sample-3	3	0.45	-1.23	1.15	-1.07	-1.31	1.22
C.I. Reactive Black 5							
Sample-1	1	-0.05	-0.04	0.04	-0.04	-0.05	0.08
Sample-2	2	0.46	-0.07	-0.40	0.40	-0.02	0.54
Sample-3	3	0.44	-0.11	-0.06	0.07	-0.10	0.46

Note: Δ*L** (difference in lightness), Δc* (change in chroma), Δ*h** (change in hue), and ΔE*(difference between two colours in an L*a*b* colour space.)

Lahore's Groundwater Depletion-A Review of the Aquifer Susceptibility to Degradation and its Consequences

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Abstract-Lahore is provincial capital of Punjab and 2nd largest city of Pakistan. Long history of groundwater over abstraction with reduced aquifer recharge has led to groundwater level recession substantially. This paper reviews the hydrology of Lahore and summarizes the results of various hydrological researches conducted for Lahore. Moreover in this paper, susceptibility of Lahore aquifer resulting due to pollution coming into and reduction in recharge resources and its consequences have been addressed. Among the main recharge sources of the Lahore aquifer, average precipitation is not adequate enough to arrest the decline in groundwater levels and River Ravi remains almost dry except in monsoon season. Peizometric levels recession, land subsidence and salt water intrusion has also contributed to its degradation. Developments like rapid increase in population, urban migration and industrialization has increased the reliance on groundwater supply manifold. On the other hand, the urbanization, industrialization and increased land impermeability have reduced the aquifer recharge significantly. Due to less consideration paid towards aquifer protection in Lahore, these impacts have been diagnosed long after their occurrence. Therefore susceptibility of Lahore aquifer to degradation has become a cornerstone of its protection policies. With the current extraction rate, increasing demographic growth and land development rates; it is more likely in future that this declining trend will end up in exhausted aquifer. If this situation remains persistent, groundwater conditions both in terms of quantity and quality are likely to worsen. Critical review concludes that energy crisis does not only mean load shedding it may be water shedding which is knocking at the doors of Lahore. Therefore there is an urgent and emergent need to solve the wicked water issues in Lahore.

Keywords-Aquifer, Lahore, Tube Wells, Depletion, Depression Cone, Ravi, City Growth

I. INTRODUCTION

Water is absolutely essential not only to human life but all the life. Indeed it is life blood. It is used for various purposes including drinking, washing, bathing, air conditioning, agriculture, industrial processes, power generation, fire protection and so many others. Almost all fresh water is groundwater which is held in underground reservoirs. Groundwater plays a very important but often an unappreciable role in social and economic well-being of urban areas. Today industrialization and urbanization has resulted in overexploitation and excessive abstraction of groundwater by pumping more and more water out. This is what is happening in Lahore where the main issue of public concern is water level recession mainly due to over pumpage compared to lesser recharge [i-vi]. Since water demands are entirely met by groundwater supply [vii], therefore the study of aquifer depletion vis-a-vis its low recharge and increasing water demands are very important.

Groundwater depletion in heavily populated and industrial city of Lahore is pushing it back to the wall. The city is also a victim of power imbalance created by India. Therefore its importance has increased all the more. Karachi which is the economic hub of Pakistan, its peace has been ravaged by ethnicity and target killing. The stability of Lahore city is important because after Karachi it is the center of economic activity. Its water crisis microcosm of the water crisis of Pakistan is likely to encounter increased use rather misuse of water resulting in swiftly declining water table. Apparently it's an issue concerning water but taking a broader view the very subsistence of is attached to it.

A. Groundwater surpassing the surface water in importance

Earth is a watery place as almost 70% of its surface is covered with water [viii]. Despite the fact that there is lot of water on the planet Earth, only about 2.5 % of the total is fresh [ix-x]. For human consumption, only about one-third of this 2.5 % is available [xi]. About 50% of the available freshwater supplies are already being used [xii]. Underground aquifers contains approximately 99% of all the liquid fresh

water [iii],[xiii] and at least one-fourth of the world's population fulfills its water needs from its supply [xiv]. In last 50 years (1950-2000), the total amount of water abstracted for human consumption has almost tripled from 1382 km^3/year to 3973 km^3/year and it is predicted that annual consumption will further increase to 5235 km^3 by 2025 [xv].

Groundwater is held in aquifers which is defined as a rock unit that yields water in usable quantities to wells or springs. The term "groundwater" is reserved for subsurface water occurring beneath the water table, in the depth of saturated soils. Precipitation which seeps down through the soil and reaches the impervious soil/rock material, saturated with water becomes part of groundwater. Groundwater is a natural source of fresh water and is an indispensable substance. The low permeability of saturation zone reduces further peracolation of water. In this way, rate of downward movement of water becomes smaller than the rate of replenishment from above. In this way, a zone of saturation is formed. The water contained in this zone is called groundwater and the top of the zone is known as water table.

Groundwater's importance is more than surface water in almost every region of the world [xvi]. Reference [xvii] estimated that about 60-70% inhabitants of Pakistan directly or indirectly dependent on groundwater for its livelihood. About 80% of the domestic water supply in rural areas is met through groundwater supply [ii],[xviii] as well as more than 50 % of drinking water supply needs. About 8.2% of renewable groundwater is annually withdrawn for human consumption [xviii]. Water crisis and challenges have different facets appearing in the form of problems concerning health, environment, poverty, scarcity, sanitation, industry, food and many others [xiii]. Following problems have been reported in arising due to groundwater over-abstraction and degradation [ii], [xix-xxvi]: (i) Lowering water tables; (ii) Wells running dry seasonally; (iii) Rising pumping costs; (iv) Competitive well deepening; (v) Land subsidence; (vi) Loss of wetlands and water bodies; (vii) Salt water intrusion and other related salinity issues; (viii) Groundwater degradation resulting from natural toxins (e.g. fluoride, arsenic); (ix) Food scarcity (critically related to water groundwater availability in developing countries including Pakistan and India); and (x) Changes in hydrological cycle.

II. Study Area

Lahore is the provincial metropolis of the Punjab province and 2nd largest city of Pakistan characterized with hot semi-arid climate. Geographically it lies between 31°15'-31°45' N latitude and 74°01'-74°39' E longitude, as shown in Fig. 1. It is bounded on the north and west by the Sheikhupura District, on the east by Wagah, and on the south by Kasur District. The Ravi River flows on the north-western side of district Lahore.

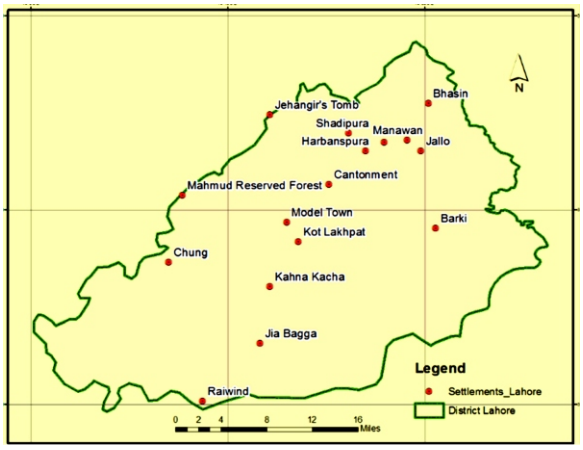


Fig. 1. Map of Study Area

Population of this already densely populated city is still growing quickly [xxvii] due to urbanization trends and migration of people to Lahore. It is entirely groundwater dependent city [xxviii]. The crux of the matter is this that exploitation of groundwater and uneven distribution of surface waters have resulted in imbalances in the demand and supply of water in the region thereby making water management the matter of utmost important concern. If the over exploitation of groundwater could be minimized, it will not only add to the natural resource in the region, it will relieve the ever increasing cost of pumping in Lahore.

III. Groundwater Problems in Lahore

In the last decade, rate of water use, in the industrial city of Lahore, has grown more than the rate of population growth. Water stress coupled with urbanization and industrialization is posing a serious threat to Lahore aquifer. The situation of water shortage is further aggravated by discharge of untreated sewage into rivers and leakage to underlying aquifer thereby causing water pollution [iv]. Another aggravating factor is water scarcity coupled with probable decrease in groundwater.

Reference [xxix] described four possible types of blue water (water in rivers and aquifers) scarcity;

1. Climate driven: due to limited run-off generation
2. Pollution driven: resulting in water quality degradation
3. Population driven: in terms of high population pressure on available water resources resulting in water shortage [xxx]
4. Demand driven: in terms of high water demand compared to water availability resulting in water stress in an area [xxx]

Presently, Lahore is facing all types of water

scarcity. It's just a game of demand and supply. To address water scarcity problems and achieve a balance between supply and demand of water, it needs improved water governance and demand management. There are two major threats to groundwater degradation; contamination and over pumping.

IV. Hydrological Setup of Lahore

Administratively Pakistan consists of four provinces, the Federal Capital Territory (FCT) of Islamabad, two disputed territories, and a group of federally administrated tribal areas. Punjab is most populous of all the provinces and have a number of locations reported to be contaminated by industrial waste water discharge [xxxi], experiencing escalating rates of aquifer depletion. Lahore, the provincial capital, is no exception to the rule. Studies report that groundwater, the main source supplying water, is vulnerable to depletion because of its excessive abstraction compared to poor recharge. This situation has arrived due to lack of property rights over water usage and either absence or no control of regulation authority [xxxii].

The book entitled "Groundwater Resources of Pakistan" by Dr. Nazir Ahmad, published in 1974, provides some useful historical insights into Lahore's hydrogeology [xxxiii-xxxiv]. Alluvial deposits of Quaternary age are underlain in this area [xxxv]. This unconfined aquifer is composed of alluvial sands and unconsolidated alluvial complex of about 400m (1300 ft) thickness [iv], [xxvii]. Despite its heterogeneity in nature due to these alluvial sediments, it behaves as homogenous and highly transmissive aquifer on large scale [iv].

Hydrogeologically, it is part of the large inter-fluvial Bari Doab which is bounded by the River Ravi to the north-west and the Sutlej and Beas River to the south-east [xxxv], as shown in Fig. 2. Due to the extension of city across the River Ravi, the Lahore aquifer now constitutes a part of the Rechana Doab (land between the River Ravi and River Chenab) [ii],[xxxvi]. The Bari Doab and the Rechana Doab are itself a part of vast alluvial plain thwarted by the River Indus and its tributaries.

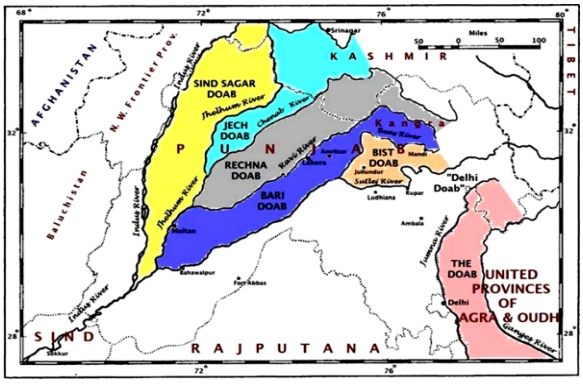


Fig. 2. Doabs of Punjab Province [lxvi]

No systematic study about underground formation was carried out till 1950. In 1954, Punjab Irrigation Department in cooperation with U. S. Geological Survey (USGS) started a study on soil and groundwater resources [xxxiii], [xxxviii]. This hydrogeological investigation included drilling of test bores, construction of test tube wells, carrying out pumping test and analyzing the data [xxxv], [xxxiii]. Test sites were drilled upto 600 ft. and each bore was 4-5 miles apart. During this regional investigation, several deep test holes were drilled in Bari Doab to determine the thickness of Alluvium, the depth to bedrock and water quality at deeper zones [xxxiv]. At a few sites bores were drilled upto bed rock and in some cases upto 1500 ft and analysis of samples collected during drilling revealed that Punjab Indus Plain consists of deposits of sand, silt and claywith appreciable amounts of kanker and other concretionary material [xxxv],[xxxviii]. The thickness of sand which is principally grey or greyish-brown colored and fine to medium grained [xxxviii] is comparatively more than silt and clay [xxxiii]. Gravels of hard rock are absent from the alluvium and coarse or very coarse sands are not common [xxxv], [xxxviii]. The unconsolidated alluvial plains of Punjab forms an extensive, highly permeable aquifer in which groundwater is generally unconfined [iii], [xxxiii]. References [xxxviii] summarized the geohydrological conditions of the Punjab plains including study area, based on the data collected during investigation study by WASID. WASID issued two reports based on its investigation; one on the geology and the other on the regional hydrology.This is the only study found providing an extensive insight into lithology of Bari Doab deposits [xxxv].

V. Aquifer Recharge and Discharge

The process by which the groundwater is replenished is called aquifer recharge. Estimation of aquifer recharge is important for following reasons [xxxv];

- The relationship between the amount of recharge and the amount of abstraction is very helpful in defining the aquifer susceptibility to the effects of excessive pumping.
- The relationship between the recharge amount and abstraction amount helps to define the area subjected to or receiving amount of recharge and needs to be protected.
- The locations as well as processes of recharge and its relationship to potential sources of pollution help in determining the pollutant loads.

The possible sources of recharge of the aquifer of Lahore are; Rainfall, River Ravi and irrigation branch canals passing through the area [iii],[xxvii],[vi]. Only two major sources will be discussed here; the rainfall and River Ravi in recharge perspective.

Reference [xxxv] presented the overview of hydrology of the Lahore region and reported a great

imbalance between the groundwater withdrawal and recharge along with absence of any regulation w.r.t water pumps installation and any groundwater model running currently.

A. Aquifer Recharge Components and factors affecting these components

i) Rainfall

Lahore lies in sub-tropical, semi-arid region. The average monthly precipitation is low and varies from month to month, as shown in Figure 3. Monsoon period in July and August months comes with highest rainfall which makes about 40% contribution to annual groundwater recharge. The average annual rainfall is of the order of 575mm, varying from 300-1200 mm. The annual potential evapotranspiration is about 1750 mm which exceeds the rainfall, thus making irrigation essential to supplement the rainfall [iii],[v-vii].

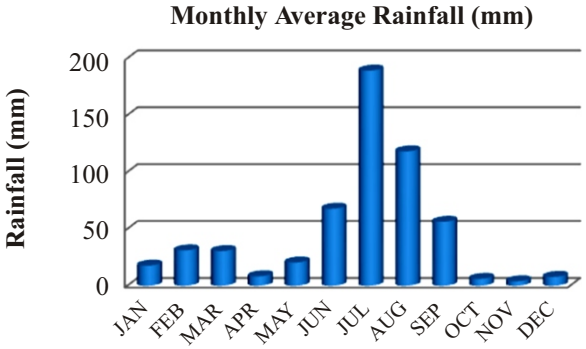


Fig. 3. Lahore Monthly Average Rainfall [xiv]

Fig. 4 shows that average annual precipitation is low and varies from and varies from year to year.

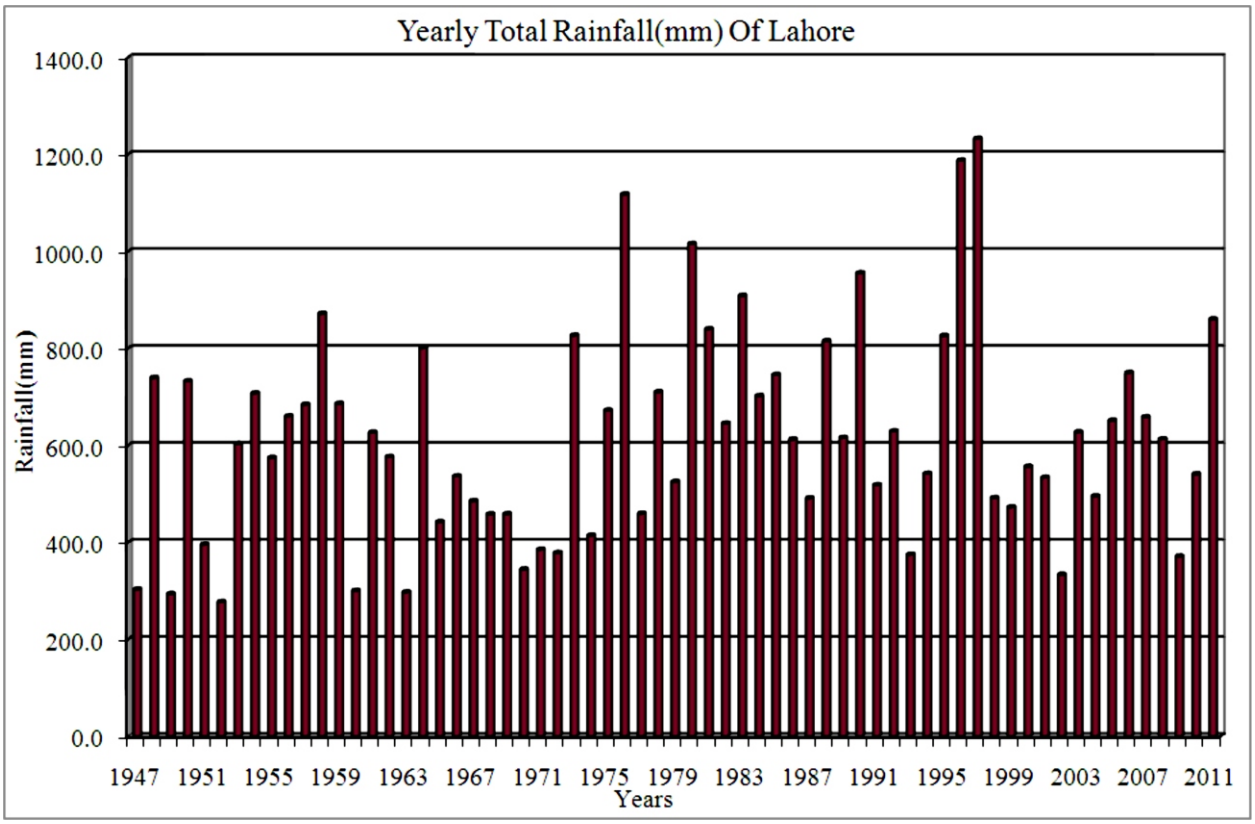


Fig. 4. Total annual rainfall of Lahore [xiv]

ii) River Ravi

The major of all sources of recharge to Lahore aquifer systems is the River Ravi originating from the neighbor country India. It is really a stumbling block that River Ravi come in Pakistan from India. This is the reason that surface flows of the river started reducing immediately after independence in 1947 ending to almost zero by 2000 when Thein Dam was constructed upstream of Madhopur head works in India [ii-iii],[xxvii],[xxxv]. It resulted in substantial lowering in water table in river adjoining areas of Lahore city. The river remains dry except monsoon season [iii]. Researches made to analyze the effect of construction of Thein dam have confirmed the lowing of aquifer recharge resulting in water table recession due to reduction in inflow of river Ravi. Study for the water

supply, sewerage and drainage of Lahore produced by Camp, Dresser and McKee (CDM) Ltd. (1976) predicted that drawdown over large parts of Lahore city after construction of Thein Dam was between 40m and 82m (also known as Ranjit Sagar Dam) and 30m to 55m before Thein Dam was constructed. However, the actual decline in water table has been less than the predictions made by Messers CDM [ii]. NESPAK conducted a research study entitled "Groundwater Resources Evaluation and Study of Aquifer under Lahore" in collaboration with Binnie & Partners Consulting Engineers, London, UK in 1988. The computer model developed by them was also being used to test the effect of construction of Thein Dam on the flow of River Ravi [vi]. Unfortunately, the River Ravi once a river that could endure life and livelihoods for thousands of people has now become dead.

Graphs in Fig. 5 shows that inflow of River Ravi has reduced substantially with the passing years thereby its contribution to underlying aquifer recharge has reduced as well and hence, endangering the aquifer sustainability.

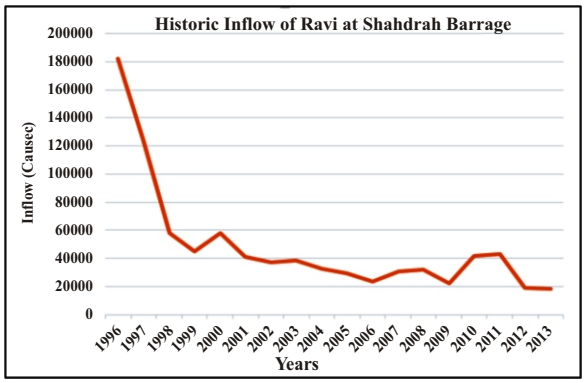


Fig. 5: River Ravi Inflow at Shahdrah Barrage

Moreover, pollution content in Ravi is much higher compared to other rivers in Pakistan. It receives a good amount of untreated urban and industrial waste waters of Lahore as well other urban and industrial waste on its way to Pakistan from the Indian catchment [iii-iv],[xxvii]. Lahore city produces 240 million gallons per day of wet sewerage [xii]. This untreated effluent is then carried into River Ravi as such where it pollutes the aquifer as it seeps down the surface. The Hudiara Drain is a major source of pollution for River Ravi. It carries agricultural and industrial waste from both India and Pakistan and discharges it into River Ravi [ii],[xxvii]. Detail of wastewater intake by River Ravi is given in Table I.

TABLE I
DETAILS OF INDUSTRIAL AND MUNICIPALITIES DISCHARGE FROM DISTRICT LAHORE [10]

No. of Industries	151
Effluent from Industries (cusec)	120
Effluent from Municipalities (cusec)	3126
Total Effluent (cusec)	3246
Treated	2
Untreated	149

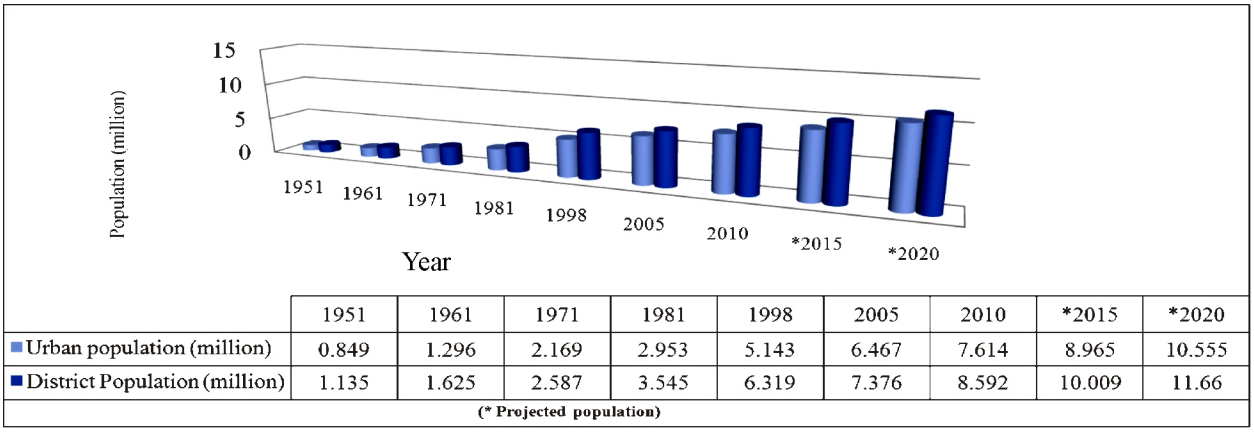
As Lahore groundwater recharge is highly dependent on river recharge [ii]; therefore a better understanding of the surface-ground water interactions is extremely important to maintain both the quality and quantity of the urban groundwater supplies. Reference [vii] proposed various types of method to recharge the depleting groundwater in Lahore artificially.These proposals include river bed modification, percolation basins, ditches and furrows, flooding, injection wells, induced recharge and modification of canal bed.

iii) Other factors affecting aquifer recharge

Lahore has been experiencing growth in various forms which is adding to aquifer stress and its susceptibility to degradation, as discussed hereunder:

1. Population growth

Lahore's population was more than 6,310,000 in 2006. It is about to become a 'mega city' with more than 10 million inhabitants, as shown in Fig. 6. Rapidly increasing population of this already densely populated urban city is adding to its water stress because the city is solely dependent upon groundwater resources for it water needs.



	1951	1961	1971	1981	1998	2005	2010	*2015	*2020
Urban population (million)	0.849	1.296	2.169	2.953	5.143	6.467	7.614	8.965	10.555
District Population (million)	1.135	1.625	2.587	3.545	6.319	7.376	8.592	10.009	11.66

(* Projected population)

Fig. 6: Lahore's Demographic Profile [xxxviii]

Table II shows how the no. of tube wells are increasing yearly because every year more tube wells are installed to meet the citizen's demands for water.

TABLE II
LAHORE'S POPULATION AND TUBE WELLS GROWTH
[xvii],[xli],[lxiii],[lxvi]

Year	Population	No. of Tube wells
1977	2602277	127
1978	2698561	133
1979	2798561	136
1980	2901949	142
1981	2952689	142
1982	3061938	142
1983	3175230	149
1984	3292714	153
1985	3414544	154
1986	3540882	181
1987	3671895	188
1988	3807755	206
1989	3948642	-
2001	7041839*	320
2010	8,592,000*	467
2011	10,000,000*	476
2012	12,500,000*	480
2013	13,200,000*	483

*Projected Values

2. Peripheral growth

Apart from population growth within city, growth along periphery is also going on in the form of haphazard subdivision of the land. Many areas lack basic infrastructure and amenities. The small communities in the city are growing like mushrooms with no proper water supply. It is a common observation that they are installing their own tube wells to fulfill their water needs without registration and any consideration of rules and regulations. With the increase in number of tube wells, the groundwater level, which used to exist at about 4.5 m below surface, has gone down to 40m. Proliferation of such unplanned urban settlements which is adding to the pressure on the groundwater resources has become a major source of concern.

3. Land Development

Lahore has practically no infiltration due to extensive industrialization and increasing heavy construction trends. Consequently, number of irrigation fields has been reduced. This factor is playing an indirect but a significant role in aquifer depletion and its susceptibility because a large part of the land has become impermeable. Urbanization affects the quality as well as quantity of the groundwater by;

- Rapid change in aquifer recharge patterns and rates
- Establishing new abstraction regimes

B. Discharge Component

i) Tube well Pumping

Before 1876, water extraction from open wells was the most common source of water [xl]. Now a days, the major source of water supply to the public is groundwater supply system of WASA/LDA tube wells, installed in different parts of the city. Total WASA abstraction of groundwater from the aquifer is 280 to 290 million gallons per day [ii]. Private Sector is also pumping a substantial amount of water, which is estimated at 150 million gallons per day. Increasing pumping rates means increasing water drawdown. Heavy groundwater abstraction in the study area has been resulted in an irregular shaped depression-cone in the central part of the city, as shown in Fig. 7.

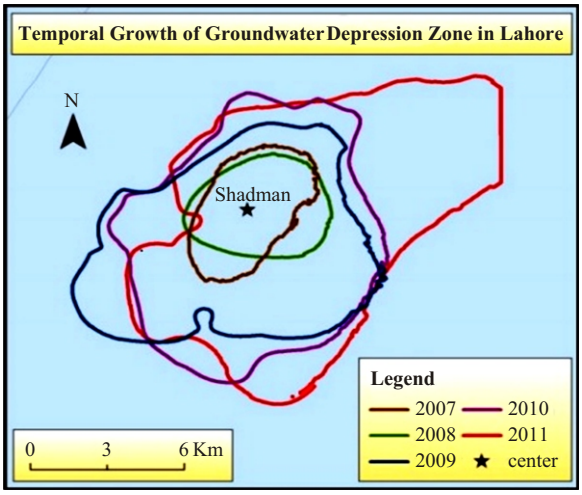


Fig. 7. Expansion of Depression Zone Contour of 38m from 2007

Moreover, it shows that the area of this depression cone has been increasing over the past few years. Depression has expanded from 16 to approximately 103 km^2 just over the span of 5 years.

Attempts have been made from time to time by various organizations to estimate the groundwater resources of the Lahore based on status of available data. The importance of groundwater for domestic, industrial and agricultural uses and its characteristics of being readily and locally available have led to overexploitation of this precious natural blessing. Technological improvement in construction of deep tube wells and pumping methods have also added to excessive abstraction from underlying aquifer, the one and only source of water for Lahore. And it has been going on since immemorial time [iii-iv].

Groundwater abstraction is the process of taking water from an aquifer, either temporarily or permanently and over abstraction may lead to

groundwater levels reduction substantially. In Lahore City, groundwater pumpage through tube wells was started in 1930, when the water table was within the suction limit (10-20 feet) of centrifugal pumps [xl]. A few small capacity (1 cusec) tube wells were installed in public sector to meet the water requirements. As the population went on increasing, more and more tube wells were of varying capacity were installed to meet water demands, as shown in Table II. Large scale exploitation started after 1960. In 1960, the number of tube wells increased to 52 and in 1988, this figure increased to 205 with total installed capacity of 670 cusecs and annual abstraction of 420 mcm. In 2000, there were 320 water supply tube wells and this figure has now reached up to 483 tube wells of varying capacity. These tube wells are operated in WASA's jurisdiction whereas there are hundreds low to medium capacity (1-2 cusecs) tube wells owned by individual citizens and private co-operative housing schemes sprouting across the city whose exact figure is not known yet. Figure 8 shows the distribution of tubewells including WASA and others in district Lahore. Due to absence of any proper legislation and compliance of the available legislation, no of un-registered tube wells are increasing expeditiously.

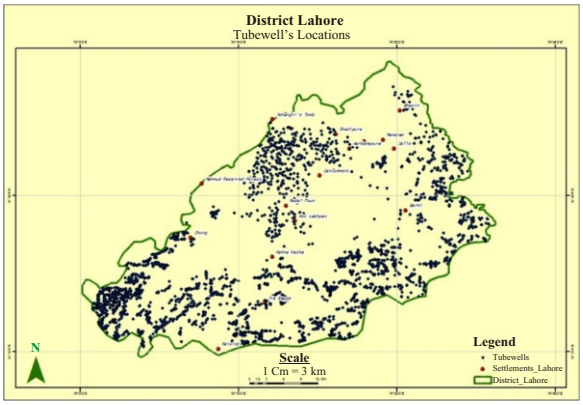


Fig. 8. Spatial distribution of thousands of tubwells installed in territory of District Lahore

VI. History of Water Table Depletion

In the study area, the groundwater level is receding due to unwise use of water for drinking, washing, bathing and other purposes. The WASA authorities are now installing more tube wells to meet public water demands. These tube-wells are being installed from 600 to 700 feet depth resulting in further more decline in falling ground water levels. This is not only threatening groundwater levels of underlying aquifer of Lahore but affecting its quality and taste as well. Rate of ground water abstraction is about 1.45 million cubic meters per day [iv]. According to the WASA report, the water table since 1961 has gone down to 61 feet on an average. Reference [iii] reported that the water table depleted by 17 feet in the Ravi Road area, 10 feet in Ichhra, 9 feet in Industrial Area KotLakhpat and Misri Shah, 29 feet in Mustafabad, 7.3 feet in Gulberg, five feet in Green Town and Baghbanpura, 2.3 feet in Data Nagar, 2 feet in Islampura and Iqbal Town, 4 feet in Samanabad, 0.6 feet in Mughalpura subdivisions, 7 feet in Shahdara and Shimla Hill, 6.4 feet in Mozang, 6 feet in Garden Town, and 4.2 feet in Township. Average decline in ground water level in Lahore is found to be 2.03 feet per year [xxxv]. Currently water level is receding at the rate of about 3 ft/yr [xli], given in Table III.

The magnitude of response of the aquifer, however, varied in different localities of the Metropolis depending upon density of wells, volume of pumping and coefficient of storage (specific yield) of water bearing formations.

TABLE III
Average Annual Rate of Groundwater Decline [lxviii]

Period	Rate of Decline	
	ft/year	m/year
1960 - 1967	0.984	0.30
1967 - 1973	1.804	0.55
1973 - 1980	1.969	0.60
1980 - 2000	2.133	0.65
2007 - 2011	2.6	0.792
2011 - 2013	3	0.9144

VII. Groundwater Management

Lahore Development Authority (LDA) is responsible for planning and land development in the Lahore Metropolitan area. The Water and Sanitation Agency (WASA) is provides water supply, sewerage and drainage collection and disposal services. Presently, WASA's monitoring network includes over 476 WASA tube wells located within study area. Water level measurements at these tube well locations are made on monthly basis. Discharge measurements are made on 100 selected water supply wells every month and about 25 water samples are collected and analyzed chemically at WASA Laboratory every day [vii]. Municipal services in the urban area are provided by the Lahore Metropolitan Corporation and the Cantonment Board.

VIII. Need of Groundwater Monitoring

Large scale taping of groundwater and over exploitation is equivalent to non-renewable water mining. Studies show that Lahore water supply is not based on groundwater but exploitation of groundwater.

This is becoming such an unprecedented case for which no other experience is found in its history. This is why study of Lahore aquifer vulnerability to degradation has become a cornerstone of groundwater sustainable management. For the sustainability of groundwater levels and quality, it is very important to be aware of the groundwater levels, quality and quality trends. Reference [xliv] stated in their report that if the world's water crisis is "mainly a crisis of governance" groundwater situation represents the merciless side of this crisis in Asia. Lahore is a very significant example of such a kind of crisis in Pakistan. There is no strict law made to limit the exploitation of groundwater in Lahore district like many other cities of Pakistan. Anyone who want and need can install his own tube well and extract water from the underlying aquifer as much as he wants. Therefore groundwater levels monitoring is needed for planning and management for sustainability of this precious resource.

Reference [xlv] described a number of objectives of groundwater level monitoring: (i) Detect impact of groundwater recharge and abstractions; (ii) Monitor the groundwater level changes; (iii) Assess depth to water level; (iv) Detect long term trends; (v) Compute the groundwater resource availability; (vi) Assess the stage of development; and (vii) Design management strategies at regional level.

IX. Impacts of Groudwater Degredation

A. Groundwater quality degradation

The region west to the Lake Michigan in the United States, includes major cities of Chicago and Milwaukee with over 12 million people is an illustration of the connection between groundwater quantity and quality management [xxxv]. Pumping from the aquifer there has caused a depression cone extending throughout large portion of the region, with groundwater level declined upto 300m at some locations. This depression cone is among the largest in the United States. High levels of arsenic are present in the upper part of the aquifer which is attributed to the mineral oxidation in newly unsaturated deposits at the top of the aquifer. Likewise, artificial recharge options to store the water in Lake Michigan aquifer have been hampered by the presence of arsenic in recovered water. Drawdown in the sandstone aquifer has also coincided with increases in the concentration of total dissolved solids (TDS) from upcoming of saline water.

Likewise urban water supply in Lahore is prone to water pollution resulting from heavy aquifer pumping in the region [xxxv], [xxviii]. Radiation and Isotope Application, a division of PINSTECH (Pakistan Institute of Nuclear Science and Technology) carried out hydrological investigation of Lahore aquifer using chemical, isotopic and numerical methods, sponsored by IAEA (International Atomic Energy Agency) and classified Lahore groundwater into four categories Hydro-chemically: (i) Calcium bicarbonate; (ii) Magnesium bicarbonate; (iii) Sodium bicarbonate; and (iv) Chloride type. Chloride type of ground-waters emerges directly from industrial activity in the area. Reference [xxviii] reported that the study showed that waters of shallow and deep aquifers are not mixing efficiently in the south east and north east areas, while in the center of the city (Gowal Mandi, Mozang, Governor House) both shallow and deep groundwater are mixing in substantial amounts. Overlapping of areas having apex of the depression-cone and peak of Cl ions in the center of the city further supports the occurrence of shallow aquifer waters mixing with the deep aquifer in the center of the city, causing deterioration in the quality of water.

In 2001, Pakistan Council of Research in Water Resources (PCRWR) conducted first national water quality monitoring program [x]. In this 5 years program, water quality analyses from different areas of the country were documented and reported in 2007. The in-depth report analyzed quality of 357 water samples collected from 23 major cities, 8 rivers, 6 dams, 4 lakes, 2 canals and one reservoir from across the country. Drinking water in every major city was found and reported unsafe including Lahore. The results of water quality analysis carried out in Lahore during 2005-2006 are given in Table IV.

TABLE IV
Results of Water Quality Analysis Carried Out During 2005-2006 [xlvii]

Sr. No.	Water Quality Parameter	Unit	Total No. of Samples Analyzed	No. of Contaminated Samples	%age of Contaminated Samples
1	As	(ppb)	16	16	100
2	Fe	(mg/l)	16	9	56
3	TI	(ppb)	16	2	13
4	Coli Forms	(MPN/100 ml)	16	8	50
5	E.Coli	(MPN/100 ml)	16	7	44

Irrigation and Power Department, Lahore publishes reports on groundwater quality and quantity monitoring for different cities of Punjab including Lahore [xv]. In their groundwater monitoring report published in 2009, water level and water quality trends in different cities of Punjab and status of groundwater monitoring has been described in volume-I while volume-II contains relevant basic details on groundwater levels and quality. For Lahore zone, groundwater quality data was collected from 389 monitoring points and water level data for 169 points. Groundwater level trends for the period 2003-2008 based on the continuous data available for 28 monitoring points for Lahore district were mapped. Perusal of groundwater data for Lahore district showed declining trends both in terms of water table and quality.

X. Other Impacts of Aquifer Depletion

A. Formation of depression zone

Due to heavy abstraction of water, water table has already gone down very deep in Lahore. Reference [xlvi] reported a continuous decrease in water table of Lahore based on the groundwater level's historical record (1993-2003). PEPA [xlvii] also reported a decline of 4m in water table in the Punjab Province capital-Lahore between 1993 and 2003. Over abstraction has resulted in cone shaped depression in Lahore aquifer as shown in Fig. 7 and groundwater researches made for Lahore region has confirmed the formation of a depression cone in the center of the city [ii-iii], [xxx], [xlviii], [xxviii], [vii], [xl]. The deepest point of the depression was located around Mozang [xii] which is now located at Shadman [xlii-xliii].

Radiation and Isotope Application, a division of Pakistan Institute of Nuclear Science and Technology (PINSTECH) carried out hydrological investigation of aquifer under Lahore using chemical, isotopic and numerical techniques, sponsored by International Atomic Energy Agency (IAEA) and a conceptual flow model was developed for Lahore aquifer which confirmed the formation of irregular shape depression cone in central part of the city [xxviii]. They predicted that if abstraction continues with the same rate, depression cone will extend south toward Raiwind and Kasur areas where polluted saline waters will likely intrude into underlying fresh aquifer. Moreover results showed that Lahore aquifer is highly vulnerable to pollution as a rapid mixing of shallow groundwater (at location near the River Ravi) and deep groundwater (at locations away from river, in the center of the city) is occurring [xxviii].

Reference [xlii] has also confirmed the formation of depression zone in aquifer under Lahore [xliv]. They also identified an eastward shifting in the depression cone, indicating higher groundwater abstraction and less aquifer recharge in the area [xlii-xliii]. This is mainly due to the recent land developments in eastern parts of Lahore city changing agricultural land into concrete structures.

B. Rise in pumping cost

The water tables lowering increases pumping cost too, thus make it uneconomical to obtain water from depths of aquifer.

C. Saline water intrusion

As already discussed, heavy abstraction in the study area has resulted in irregular shape depression cone in central part of the city [xlii],[xv],[xxviii],[xliv] and activated saline water movement from adjacent areas and from depth of aquifer thus resulting in upper aquifer's salinization [xxviii],[xliv]. Lahore aquifer being unconfined is highly vulnerable to pollution as a rapid mixing of shallow groundwater (at location near the River Ravi) and deep groundwater (at locations away from river, in the center of the city) is occurring. Few years ago, there was only a single depression zone under the city. Now not only this depression zone has expanded over even larger area, few other small depression zones have appeared due to the stress on the aquifer in those regions [xliii].

D. Danger of Land subsidence

Land subsidence occurs when a large amount of groundwater has been drawn from certain type of rocks and soils. These soils and rocks may collapse when heavy abstraction of groundwater s made because water is partially responsible for holding ground up. Increasing development of land, construction of new and high buildings, and exploitation of groundwater may result in and exacerbate land subsidence. But still Lahore is saved from land subsidence just because there is a hard-pan of clay under the city [vii] which is supporting the buildings but it may eventually collapse if the over-pumping of groundwater continues without any curative measures for recharging the aquifer.

XI. Epilogue

It is more likely that aquifer of Lahore will become non useful in future in view of present groundwater conditions because present state of groundwater levels and quality in Lahore is miserable. Therefore there is a dire need for understanding the dynamics and factors responsible for this wretched situation. Making a close critical analysis based on previous studies regarding groundwater problems in the study area, key messages are:

1. Over exploitation and degradation of groundwater is going on.
2. Installation of new tube wells cannot be stopped.
3. There is a great need of having regular watch on continuously lowering water table in the study

Area.

4. In Lahore, rapidly increasing trends of urbanization and industrialization coupled with dependence of city solely on groundwater is deteriorating both the quality and quantity of underlying aquifer.
5. Heavy groundwater pumping is the sole cause of reduced water table which has already gone down below 43m in many areas.
6. Besides, tube well's close spacing is another factor accelerating the aquifer depletion.
7. Groundwater lowering if not arrested in time may result in land subsidence in Lahore.
8. Saline water intrusion is occurring due to uncontrolled groundwater pumping.
9. The central part of the city is likely to undergo the highest decline in water levels, making groundwater pumpage very expensive in these areas.
10. Installation of more tube wells without taking proper regulation into consideration will pollute area's remaining groundwater resources in near future.

XII. RECOMMENDATIONS

Apparently the issue of water abstraction is likely to perpetuate rather exacerbate in coming years. Natural recharge to underlying aquifer has been reduced considerably and flow of River Ravi is almost zero. So there is a great need to recharge the aquifer artificially and stop installation of new tube wells at least in the boundary of Lahore city. Groundwater is valuable but vulnerable resource that requires management which should aim at protecting the quality and quantity of groundwater [li-lii]. If due attention will not be paid, Lahore will have to face the situation similar like Quetta and Karachi. Following recommendations can be followed to avoid worse situations likely to occur in years to come:

1. Groundwater levels monitoring is needed for sustainable management of this precious resource [liii-liv].
2. There is great need of taking steps for public awareness about the dwindling status of groundwater [lv] in order to reduce the un-wise water usage.
3. Well spacing is a major factor which can help to arrest the groundwater draw downs and keep it at a minimum level. Concentration of tube wells in an area is generally not recommended. In 1976 , it was recommended to keep 4000 ft. well spacing in order to keep utilizing groundwater as a water source for Lahore for the very long term [xlix].
4. To make small ponds or water reservoir either in or near River Ravi for water storage during flooding. This may serve as an alternative option for aquifer recharge and contribute to save it from exhausting.
5. To develop an early warning system for Lahore to forecast groundwater quality and quantity trends [iii].

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Analysis of Different Power Grid Segmentation and Transmission Schemes for Power System Security Improvement

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***Abstract*-**This paper explores the power grid segmentation concept for power system stability improvement in detail. First, the firewall property of grid segmentation is investigated for a two area network. Then two HVDC technologies, LCC and VSC, are compared for the same network. A two area VSC-AC segmented network is then compared with two area VSC segmented network. Suitable segmentation topology and suitable number of VSC segmented areas are then investigated. Simulation results show that grid segmentation offers network stability during fault conditions and VSC is the most suitable choice for segmentation over LCC. Results further show that having large number of DC segmented areas and using the radial segmentation topology improves the stability of the overall system. All the simulations were carried out in PSS®E software provided by SIEMENS.

***Keywords*-**HVDC System, Grid Segmentation, Stability, Voltage Source Convertors, Line Commutated Convertors.

I. Introduction

In the earlier days, DC (direct current) systems were used for electrical power generation, transmission and distribution. Due to low voltage levels and high losses associated with DC systems in the past, the electrical power generating sources had to be located very close to the electrical loads. With the invention of AC system, particularly the transformer, the problems of high transmission line losses and location of generating stations were solved. The development of power electronics and semi conductor devices resulted in significant improvement in the system for transmitting DC power at high voltage levels. This system is called high voltage direct current (HVDC) system.

This paper is structured as follows. In section II, merits and demerits of HVDC system, its latest applications and research work carried out in power grid segmentation is discussed. In section III core HVDC technologies and power system stability is discussed. Section IV discusses the test systems under study in this research. Section V compares and analyzes the simulation results. Section VI contains the conclusion.

II. Literature Review

The advantages and disadvantages of HVDC system have been discussed in [i]. HVDC system has found many applications, like power transmission over a long distance, power transmission through cables, offshore transmission, power transmission to urban areas and grid segmentation, since its evolution in the late 1950s [i-iii].

The main components of HVDC system have been discussed in detail in [iii-iv]. Convertor is an integral component of HVDC system. There are three convertor technologies available namely line commutated current source (LCC), capacitor commutated convertors (CCC) and voltage source convertors (VSC).

Grid segmentation is one of the modern applications of HVDC technology in which a huge power grid is divided into smaller segments which are then connected to each other through HVDC links. The concept of grid segmentation was introduced by authors in [v-viii]. Increased reliability of renewable sources integration [ix], efficient congestion management [ix], improvement in power system stability, power transfer capability and reduction of cascading outages and blackouts are the proposed advantages of grid segmentation [vi -xi].

The authors concluded that VSC-HVDC technology gave better transient stability results than LCC-HVDC technology and HVAC after studying a two-area hybrid HVDC-HVAC system. A three phase short circuit fault was applied and bus voltage, bus angle, generator speed and rotor angle were analyzed [xii]. Two-area power network containing VSC-HVDC links gave better results, with respect to system stability, than that containing pure AC links. Generation loss and tripping of transmission lines were the disturbances applied [xiii]. A two area network containing VSC-HVDC links in parallel with AC links

is shown to be more stable than that containing only the AC links [xiv].

The research work presented in this paper is divided into four cases. In the first case, a comparison between LCC, VSC and AC segmentation schemes is made for a two area network. This network is not a hybrid HVDC-HVAC network as in [xii]. Second case investigates whether it is better to segment a power grid by VSC links only or segment it by VSC links in parallel with an AC link. The third case involves the study of the effect of increasing the number of HVDC-segmented areas on the stability of the overall system. The fourth case involves study of three possible connection topologies of grid segmentation using VSC links. LCC and VSC links refer to HVDC transmission lines based on LCC and VSC convertor technologies respectively. All the simulations were carried out in PSS®E software provided by SIEMENS.

III. Core HVDC Technologies and Power System Stability

3.1 Core HVDC technologies

The different HVDC technologies present are:

a) LCC / CSC (Classical) HVDC
b) CCC-HVDC
c) VSC-HVDC/ HVDC PLUS/ HVDC LIGHT

A. LCC- HVDC technology

LCC stands for line commutated current source convertor. This technology is also called CSC or classical HVDC. In this technology, thyristors are used for switching purpose. The switching circuit consists of three phase full wave bridge. A strong synchronous voltage source is required for commutation [ii].

B. CCC- HVDC technology

CCC stands for capacitor commutated convertors. In this technology, series capacitors are connected between valves (built up with thyristor modules connected in series) and convertor transformers. They provide reactive power compensation automatically and improve voltage stability by providing commutation voltage.

C. VSC-HVDC technology

VSC stands for voltage source convertors. This technology is also known as HVDC LIGHT or HVDC PLUS. In this technology, self commutated IGBTs are used for switching purpose. Reactive power is not consumed by VSC-HVDC convertors. They improve voltage regulation of AC system and can be used as a source of balanced three phase voltage. There is no commutation problem in this technology**.** The authors in [iii-iv] have done detailed comparison of LCC and VSC convertors.

3.2 Power system stability

Stability of a power system is divided into three categories; Rotor angle, Voltage and frequency stability. Rotor angle stability gives idea about synchronism of synchronous machines after a disturbance in the power system. A power system is voltage and frequency stable if all of its buses maintain the steady state voltage and frequency respectively after a disturbance [xv]. In this paper the first two categories of stability are considered while speed of the generator is considered to study the frequency stability. The rotor angle studied in this paper is relative to the swing bus.

IV. System Under Study

Three cases are studied in this paper. In all of the cases, all of the generators, along with their exciters and turbine governors, use built-in models of the software.

Case 1

In this case the system shown in Fig. 1 is used as a test case provided by NTDC (National Transmission and Dispatch Company) limited Pakistan. It is a two-area four machine network. Bus 12 and 25 are the swing buses. Three scenarios are studied; Scenario A: Area 1

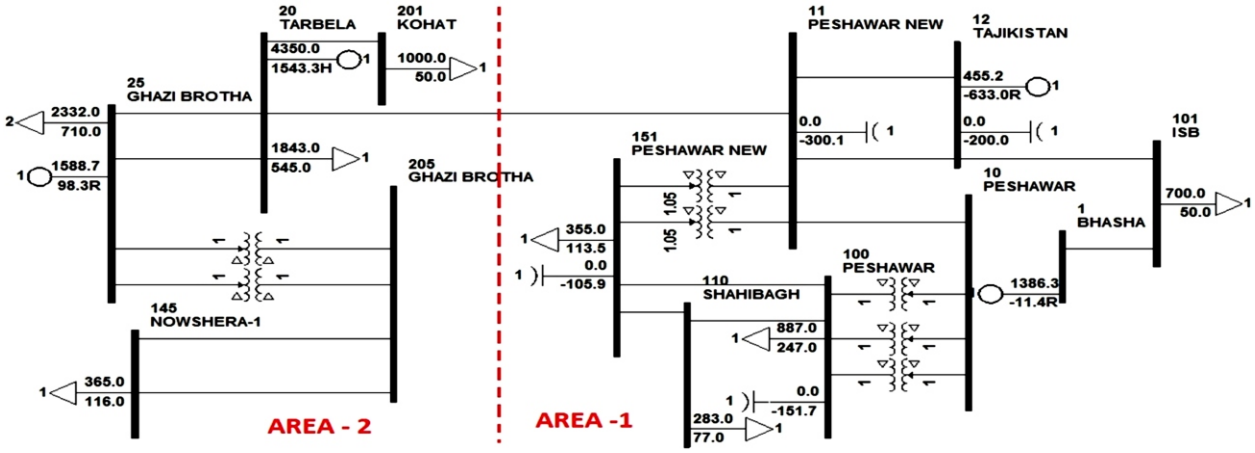


Fig. 1. Two-area four machine network under study for case 1 and case 2

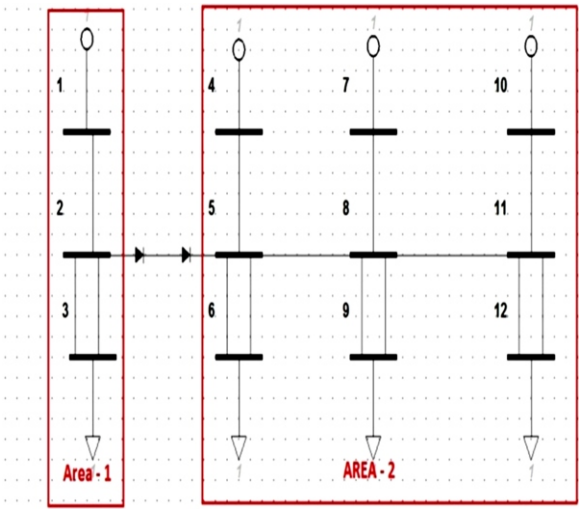
and 2 are separated by AC transmission line between bus 11 and 20 (AC segmentation). Scenario B: area 1 and 2 are separated by LCC link between bus 11 and 20 (LCC segmentation). Scenario C: area 1 and 2 are separated by VSC link (VSC segmentation) between bus 11 and 20.

Case 2

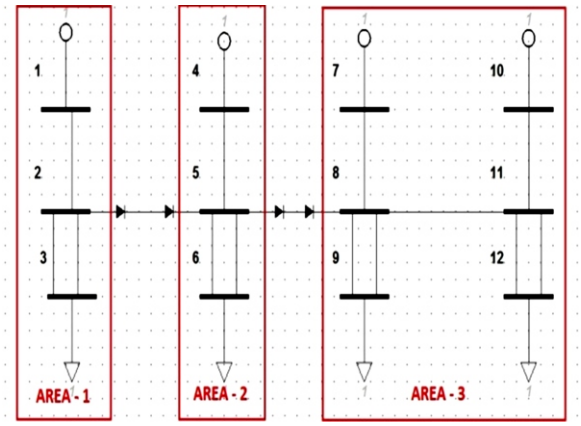
In this case the system that is studied is shown in Fig.1. Three scenarios are studied; Scenario D: In this scenario, only an AC link is present between bus 11 and 20 (AC segmentation). Scenario E: VSC link is connected in parallel with an AC link between bus 11 and 20 (VSC-AC segmentation). Scenario F: Only VSC link is connected between bus 11 and 20 (VSC segmentation).

Case 3

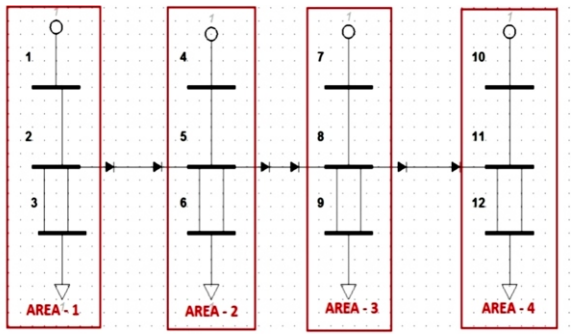
In this case of the research three scenarios are studied for a four area system each containing a generator , load , three buses and three transmission lines; Scenario G: The system under study is as shown in Fig. 2a. It's a two area VSC-segmented network i.e. area 1 and 2 are separated by a VSC link. Scenario H: In this case there are two VSC links between areas 1, 2 and 3 as shown in fig. 2b. It's a three area VSC-segmented network. Scenario I: In this case there are three VSC links between areas 1, 2, 3 and 4 as shown in fig. 2c. It's a four area VSC-segmented network. Bus 1, 4, 7 and 10 are the swing buses.



(2a)



(2b)

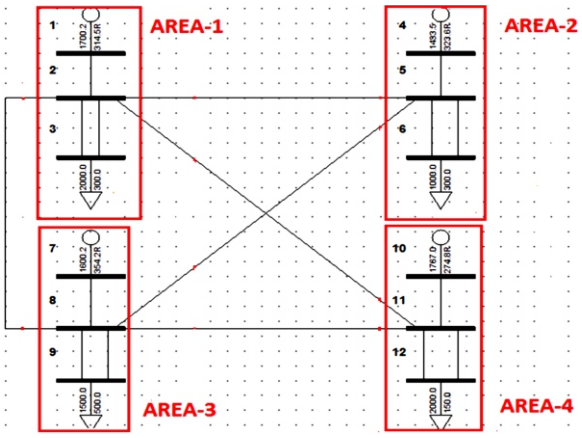


(2c)

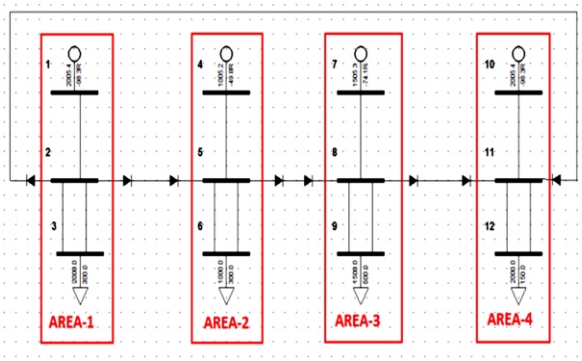
Fig. 2. Four area network under study for case 3. (a) Scenario G: One VSC link (b) Scenario H: Two VSC links (c) Scenario I: Three VSC links

Case 4

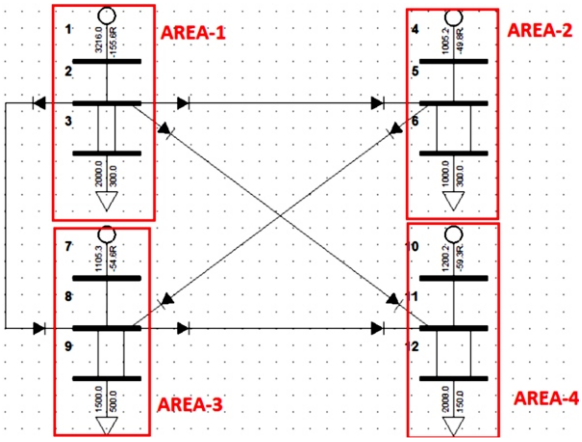
In this case of research, four types of connection topologies of a four area network are studied; Type 1: All the areas are interconnected to each other by AC links as shown in fig. 3a. Type 2: All the areas are connected in a ring as shown in fig. 3b. Type 3: All the areas are interconnected by VSC links as shown in Fig. 3c. Type 4: All the areas are radially connected as shown in Fig. 3d. Bus 1, 4, 7 and 10 are the swing buses.



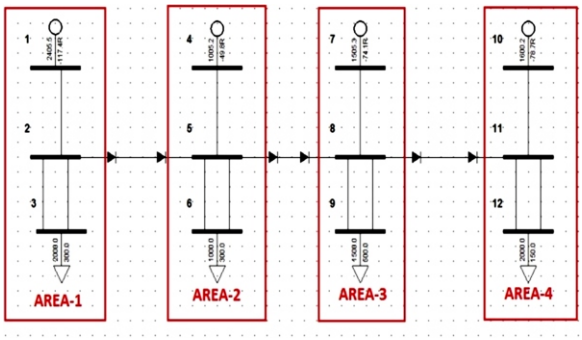
(3a)



(3b)



(3c)



(3d)

Fig. 3. Four area network under study for case 4. (a) Type 1: AC interconnection (b) Type 2: Ring topology (c) Type 3: VSC interconnection (d) Type 4: Radial topology

V. Simulation and Results

Case 1

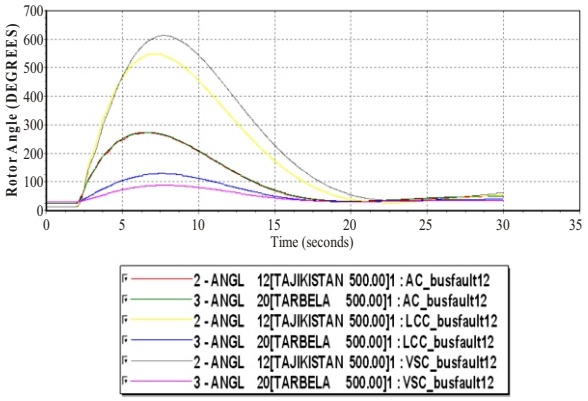
The simulation is carried out for 30 sec. The different types of disturbance, applied one at a time to the system, are 3 phase bus fault, 3 phase line fault, tripping of transmission line, unbalance double line to ground bus fault. Duration of all types of disturbance is 0.18sec.

Fig.4a shows the change in rotor angle of generators at bus 12 (area-1) and 20 (area-2), during bus fault at bus 12 for scenarios A, B and C. The red, yellow and grey curves represent rotor angle of bus 12 (area-1) generator for AC, LCC and VSC segmentation respectively. The green, blue, and purple curves represent rotor angle of bus 20 (area-2) generator for AC, LCC and VSC segmentation respectively.

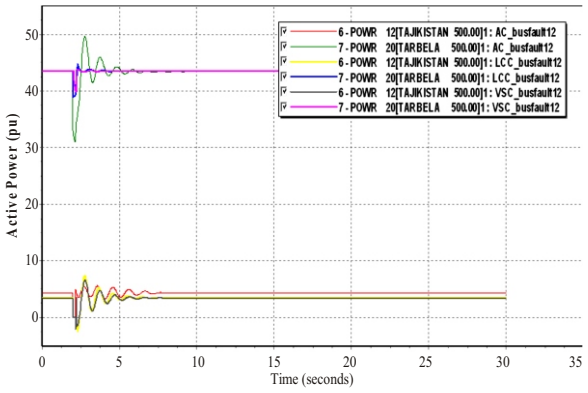
In scenarios B and C, the rotor angle (blue and purple curve respectively) of generator at bus 20 in area-2 experienced lesser magnitude change than in scenario A. Further when VSC link is used (scenario C), the magnitude change is the least making it the best choice for segmentation.

Other parameters like active power, Fig.4b, reactive power, Fig. 4c, terminal voltage, Fig. 4d and speed deviation, Fig. 4e of generators were also analyzed and VSC segmentation gave the best results in terms of magnitude change and settling time for bus fault at bus 12.

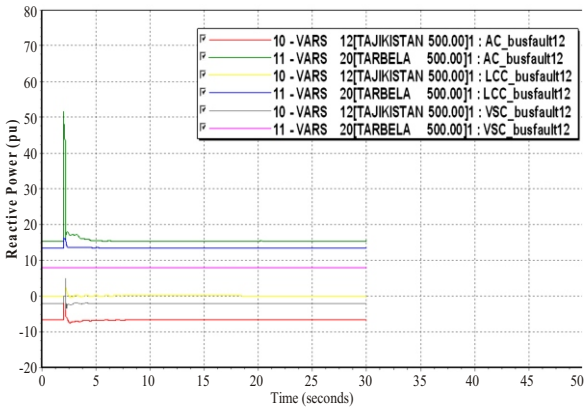
VSC segmentation also proved to be the best when other types of disturbances, like 3 phase fault at transmission line between bus 10 and 11, Fig. 5a, 1500MW line trip in area 1, Fig. 5b and 5c and double line to ground unbalance bus fault at bus 12, Fig. 5d, were applied. Magnified view of bus 20 curves of Fig. 5b is shown in Fig. 5c. VSC again proved to be the best when disturbance was applied in area-2, Fig. 6.



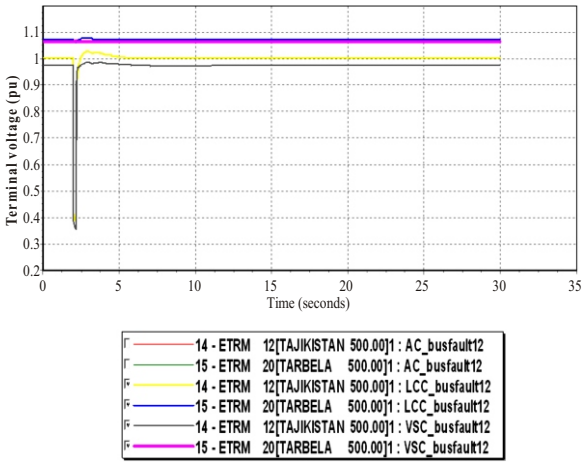
(4a)



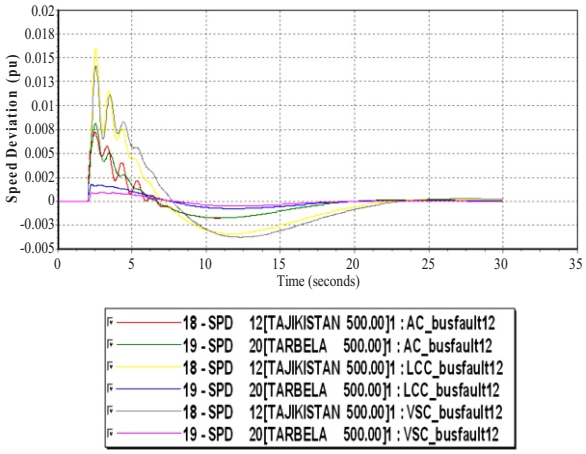
(4b)



(4c)

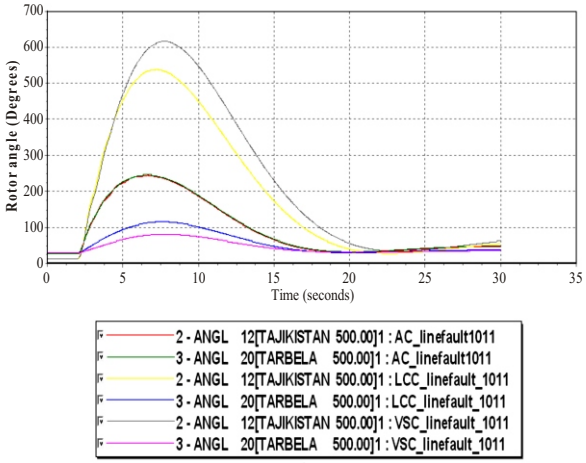


(4d)

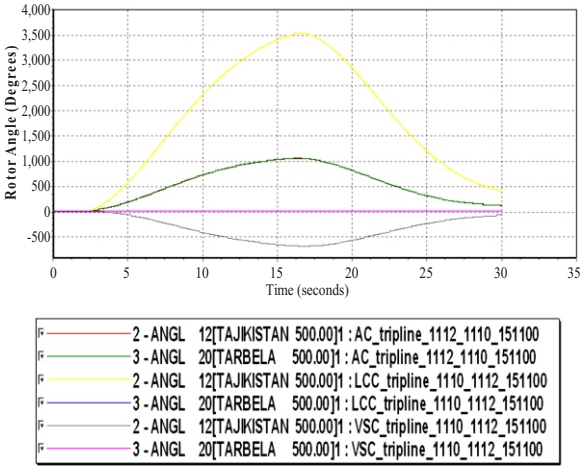


(4e)

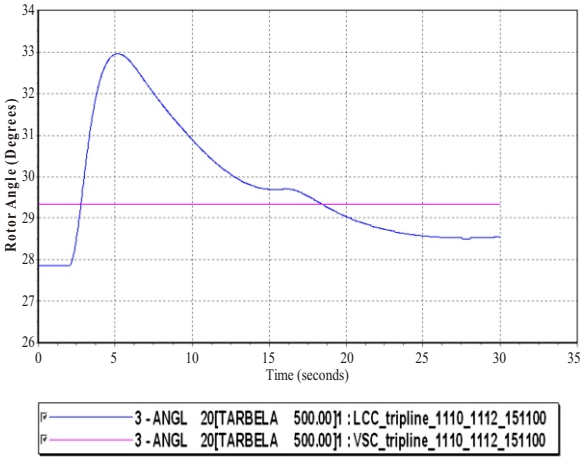
Fig. 4. Plots of different parameters of generator under study for scenarios A, B and C. (a) Rotor angle (b) Active power (c) Reactive Power (d) Terminal voltage (e) Speed deviation



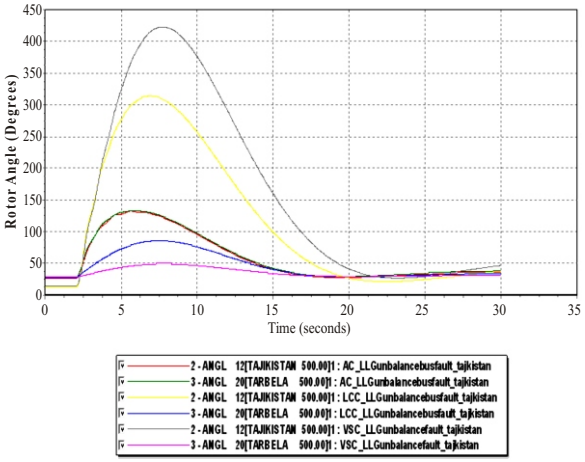
(5a)



(5b)



(5c)



(5d)

Fig. 5. Rotor angle plot for different types of disturbances (a) Line fault (b) 1500MW Line trip (c) Magnified view of Fig. 5b (d) unbalance double line to ground fault

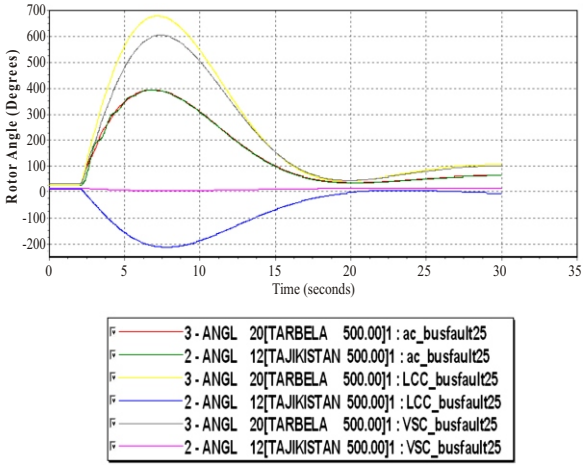
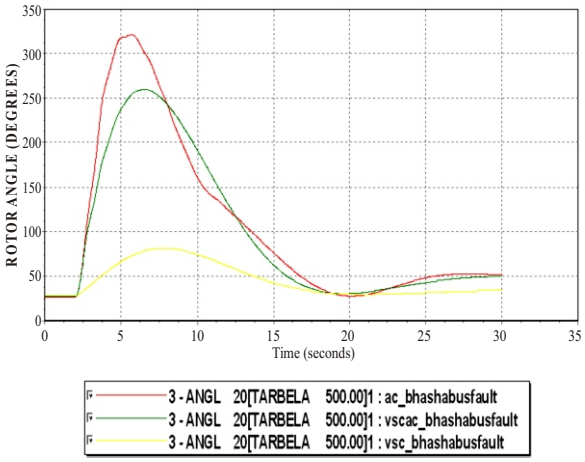


Fig. 6. Rotor angle plot for bus fault at bus 25 in area 2.

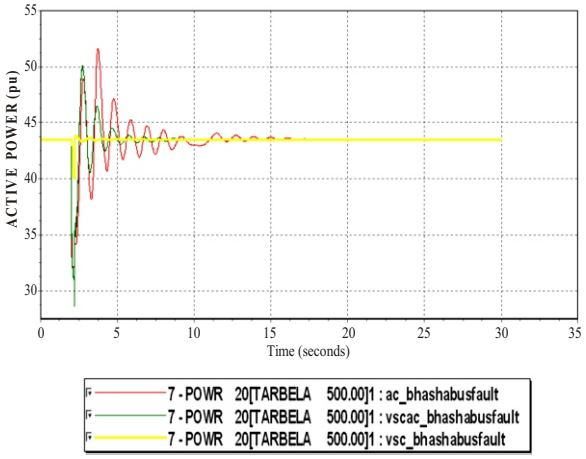
The results in case 1 clearly show that DC links (VSC or LCC) were able to minimize the propagation of disturbance from area-1 to area-2 and vice versa hence providing more stability to the overall network. Results also show that VSC is better than LCC for segmentation.

Case 2

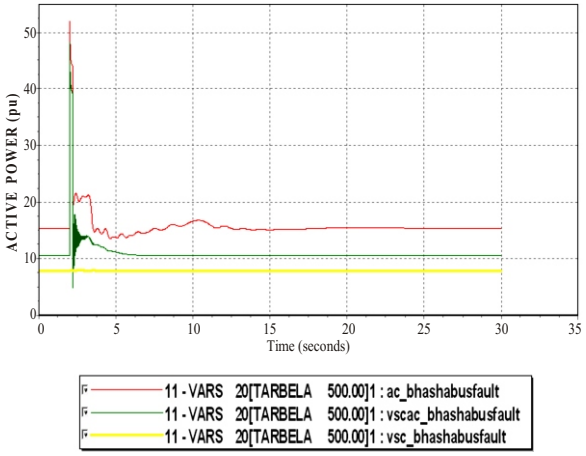
The disturbance applied is 3 phase bus fault at bus 1. Duration of fault is 0.18sec. Simulation results are shown in Fig. 7a-7e. Each plot represents different parameters of bus 20 generator. In each plot the red, Green and yellow curves represent scenarios D, E and F respectively.



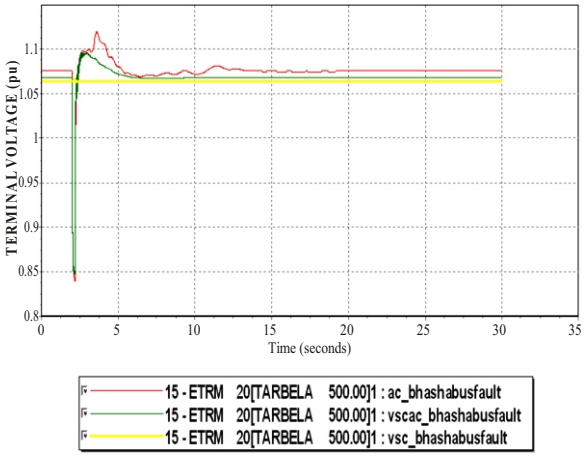
(7a)



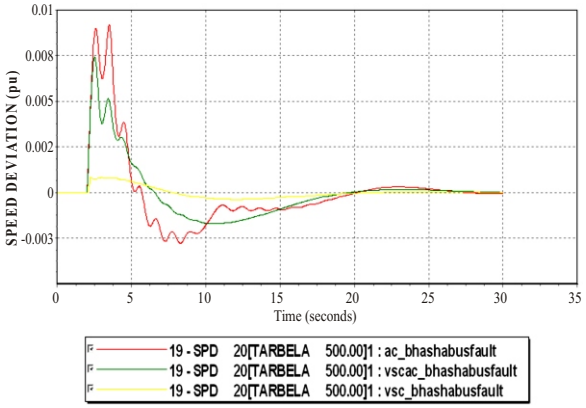
(7b)



(7c)



(7d)



(7e)

Fig. 7. Plots of different parameters of bus 20 generator under study for scenarios D, E and F. (a) Rotor angle (b) Active power (c) Reactive Power (d) Terminal voltage (e) Speed deviation

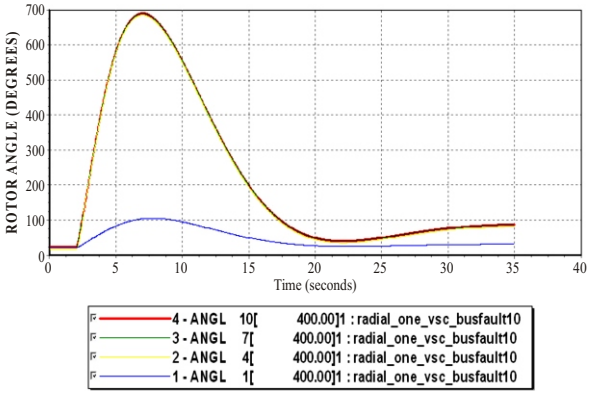
In Fig. 7a, the magnitude change of rotor angle is lowest for scenario F (VSC segmentation) and highest for scenario D (AC segmentation).

In Fig. 7b the magnitude change and settling time of generated power is highest in scenario D and least in scenario F. Same is the case in Fig. 7c. Here the yellow curve is almost straight. In Fig.7d the drop in generator terminal voltage magnitude and settling time is highest in scenario D while in scenario F there is no significant drop. In Fig. 7e generator speed deviation is highest in scenario D and lowest in scenario F.

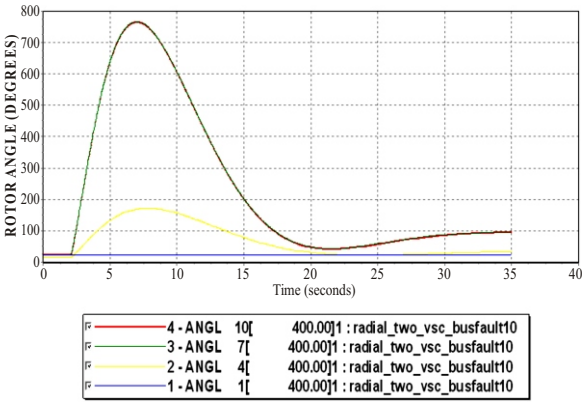
Hence it can be concluded that the overall system is more stable during a fault when only VSC technology is used for system segmentation. Performance of AC segmented and VSC-AC segmented systems during a fault are almost the same as shown by the red and green curves in each plot from Fig. 7(a-e).

Case 3

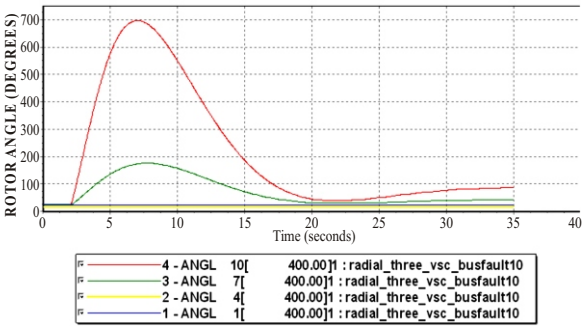
A three phase bus fault is applied at bus 10 for 0.18 sec. Simulation results are shown in Fig. 8-11. In Fig. 8-11 the red, green, yellow and blue curves represent parameters of generator at bus 10, 7, 4 and 1 respectively.



(8a)



(8b)

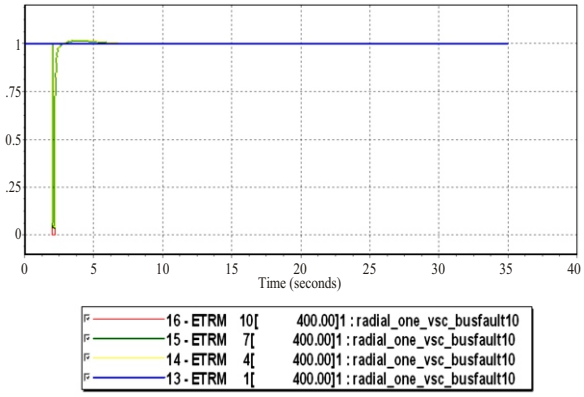


(8c)

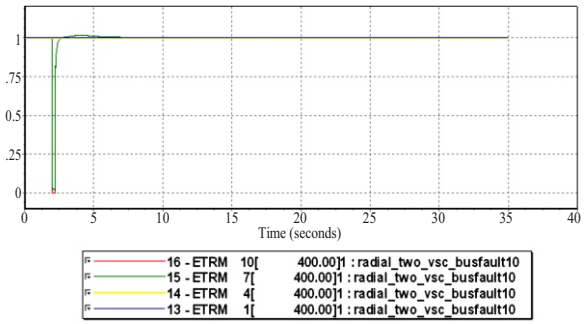
Fig. 8. Rotor angle plots for different scenarios of case 3 (a) Scenario G: two area VSC-segmented network (b) Scenario H: three area VSC-segmented network (c) Scenario I: four area VSC-segmented network

Fig. 8 (a), (b) and (c) shows the rotor angle of generator for scenarios G, H and I respectively. Rotor angle change at bus 1 (area 1) improves from about max 100 degrees in scenario G (two area VSC-segmented network) to 0 degrees in scenarios H (three area VSC-segmented network) and I(four area VSC-segmented network). Similarly rotor angle change at bus 4 (area 2) improves from about max 700 degrees in scenario G to max 200 degrees in scenario H and finally to 0 degrees in scenario I. Rotor angle change at bus 7 (area 3) also experience the same trend. Whereas rotor angle change at bus 10 (area 4) remains almost the same for all the scenarios.

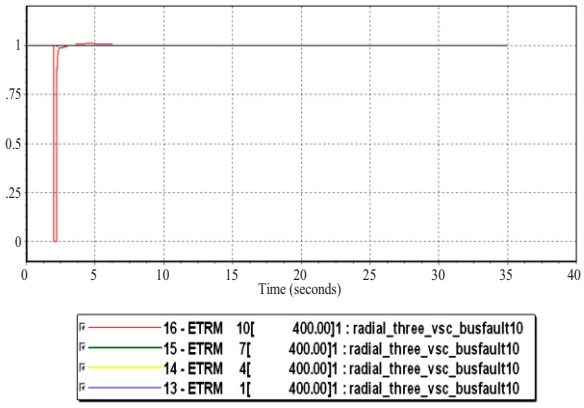
Fig. 9(a), (b) and (c) shows the magnitude of terminal voltage of generator for scenarios G, H and I respectively. Terminal voltage drop at bus 1 is 0 volts in scenario G and remains 0 in scenarios H and I. Terminal voltage drop at bus 4 improves from 0.956 degrees in scenarios G to 0 degrees in scenarios H and I. Similarly terminal voltage drop at bus 7 improves from 0.963 degrees in scenarios G to 0 degrees in scenarios I. Scenario I showed best result for other parameters as well like generator active power (Fig. 10a-10c) and speed deviation (Fig.11a-11c) as well. Hence it is concluded that having large number of DC segmented areas improves overall system stability.



(9a)

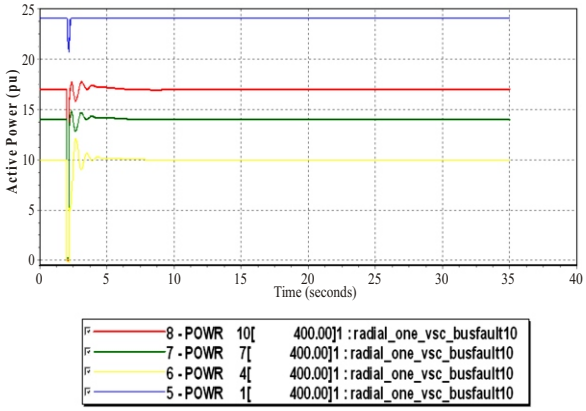


(9b)

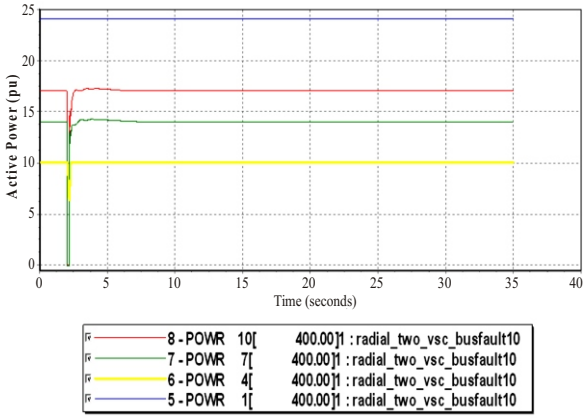


(9c)

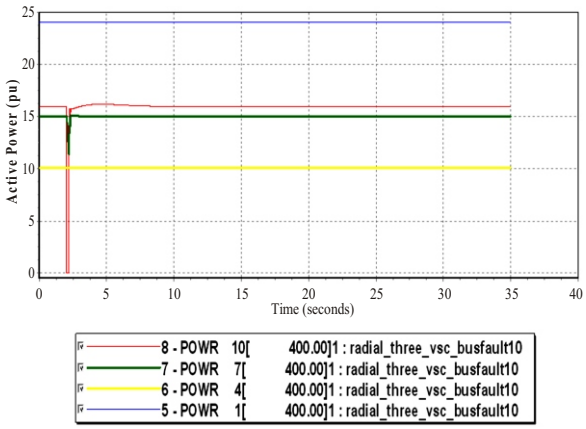
Fig. 9. Terminal voltage plots for different scenarios of case 3 (a) Scenario G: two area VSC-segmented network (b) Scenario H: three area VSC-segmented network (c) Scenario I: four area VSC-segmented network



(10a)

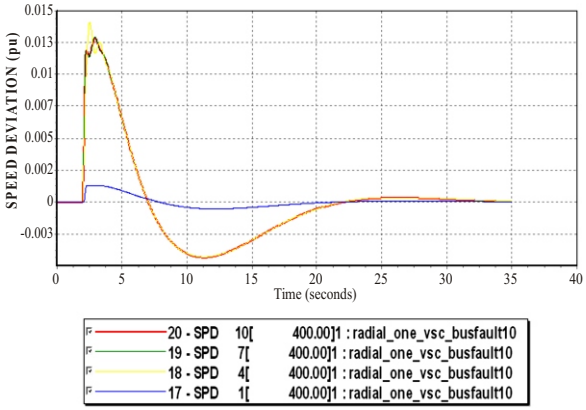


(10b)

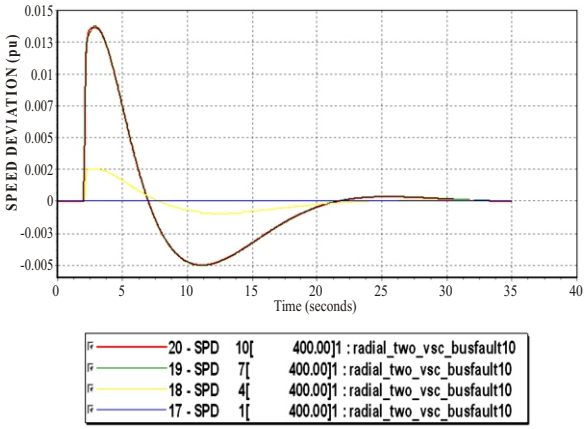


(10c)

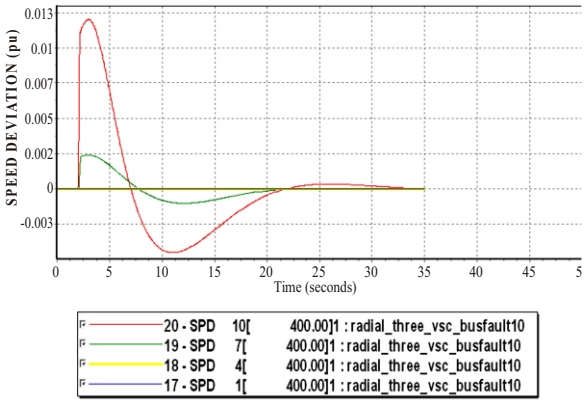
Fig. 10 Active Power plots for different scenarios of case 3 (a) Scenario G: two area VSC-segmented network (b) Scenario H: three area VSC-segmented network (c) Scenario I: four area VSC-segmented network



(11a)



(11b)

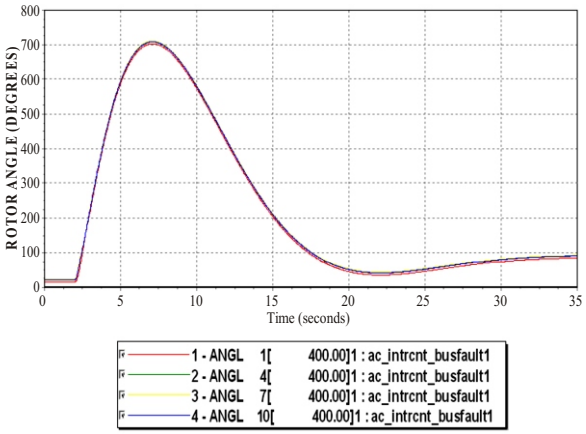


(11c)

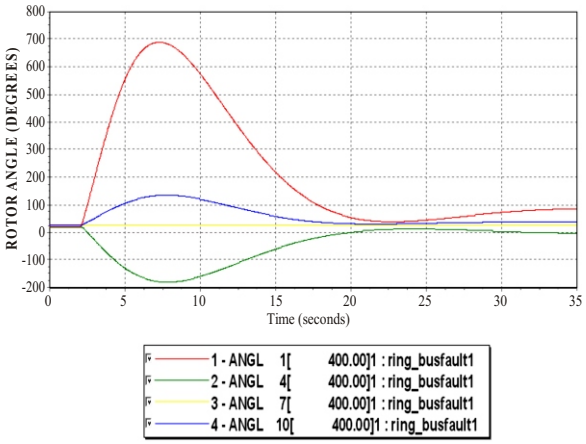
Fig. 11. Generator Speed deviation plots for different scenarios of case 3 (a) Scenario G: two area VSC-segmented network (b) Scenario H: three area VSC-segmented network (c) Scenario I: four area VSC-segmented network

Case 4

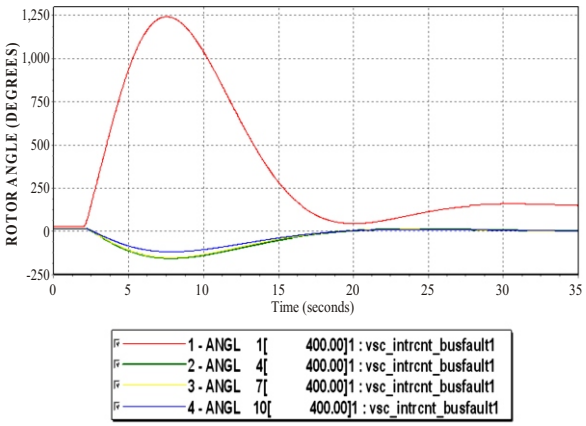
A three phase bus fault is applied at bus 1 (area 1) for 0.18 sec. Simulation results are shown in Fig.12(a-d). The red, green, yellow and blue curves represent rotor angle of generator at bus 1, 4, 7 and 10 respectively.



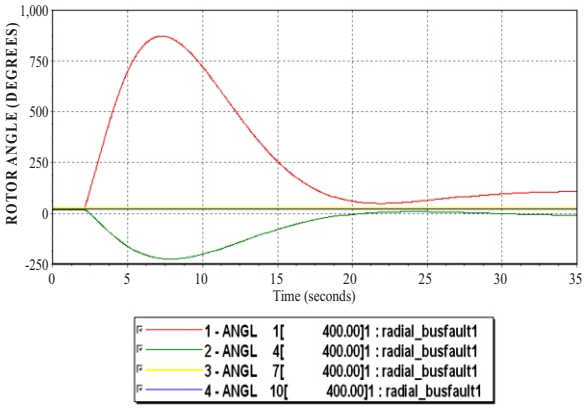
(12a)



(12b)



(12c)



(12d)

Fig. 12. Rotor angle plots for different connection types (a) Type 1: AC interconnection (b) Type 2: Ring topology (c) Type 3: VSC interconnection (d) Type 4: Radial topology

Fig. 12a represents rotor angle of generators for connection type 1 and shows that all the areas experience rotor angle change following a disturbance. Fig. 12b represents rotor angle for connection type 2 and shows that area 3 rotor angle (yellow curve) change is negligible while area 2 (green curve) and 4 (blue curve) experience change. Fig. 12c represents rotor angle for connection type 3 and shows that all the areas experience rotor angle change but less than the one they experienced in type 1 connection.

Fig. 12d represents rotor angle for connection type 4 and shows that area 3 and 4 under goes negligible rotor angle change.

Area 4 is affected in type 2 connection because it is directly attached to the area, where fault occurred, through VSC link while in type 4 connection it is indirectly attached to fault area 1 and hence remained unaffected. Similarly all the areas in type 3 connection is affected because of their direct connection with the fault area 1 through VSC links.

This research shows that type 4 connection (radial) is the best as more number of areas is stable. Further, areas farther away from fault area are more stable. Also this type of connection uses minimum number of VSC links as compared to type 3 and type 4 connection and hence reduction in the overall system cost.

VI. Conclusions

In this paper, the concept of grid segmentation was thoroughly explored in four cases. Case 1 concludes that HVDC segmentation acts as a firewall by minimizing the propagation of disturbance to healthy areas of the power network. In this case it is also concluded that Voltage source convertor (VSC) technology, when used alone, is better than the line commutated convertor (LCC) technology for grid

segmentation. In case 2 it is shown that VSC grid segmentation is better than VSC-AC segmentation. Case 3 concludes that having large number of HVDC segmented areas improves overall system stability. Case 4 of the research concludes that radial VSC connection is more suitable than ring and interconnected connection as it improves overall system stability. The segmentation concept is relatively new. Some areas like its implementation from economic point of view, finding out suitable location for installing HVDC links and application of this concept in detailed models of power system should be considered in future study.

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Modeling Greenhouse Gases Emissions from MSW of Lahore

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Abstract-In this study, an attempt is made to evaluate the characteristics of MSW generated from the Ravi Town, Lahore and assess the level of greenhouse gases (GHG) emissions along with the associated global warming potential (GWP), from the collection and landfilling operations of the waste. The MSW of the Ravi Town mainly consists of kitchen waste, covering 29.19% during Season 1 (late summer) and 59.66% during Season 2 (winter). Among the GHG, a total 40,947,871.866 kg of CO_2, 9,855,720.054 kg of CH_4, and 269.320 kg of N_20 is released into environment with a combine GWP of 248,001,482.237 kg for MSWM of Ravi Town. As MSW contains 56% biomass in Season 1 and 60% in Season 2 so the significant global warming potential can be reduced through integration of bio-gasification. This would not only reduce substantial greenhouse gases emissions but also produces energy and compost, a suitable soil conditioner with economic returns.

Keywords-Municipal Solid Waste, IWM-2 Model, Greenhouse Gases, Bio-Gasification

I. INTRODUCTION

In the recent years, a significant increase in the solid waste generation has been occurred in the less developed countries due to population explosion, rapid urbanization, change in lifestyle and standards of living [i]. At the same time, the proper management of municipal solid waste (MSW) is highly neglected in this part of the world [ii]. The poor management of MSW causes a significant emission of greenhouse gases (GHG), globally it accounts 5% of the total GHG emissions [iii]. The GHG in the atmosphere traps the heat, leading to global warming and climate change [iv]. Therefore, the waste management shall not only consider the safe treatment and disposal of MSW but also the proper management of GHG generation [v].

In Pakistan, the sixth most populated country of the world with 35% urban population, 55,000 tons of MSW is generated each day in the urban areas [vi]. As mentioned by [vii], the city of Lahore with population 8 million generates 5000 tons MSW per day. The management of MSW in Lahore only comprises of collection of the waste and its open dumping at designated sites. Moreover, the amount of waste being produced in the cities is beyond the capability of the municipal authorities due to lack of the organizational framework, budget and multi-dimensional and the complicated system [vi]. To overcome these issues, an integrated waste management model is needed. Life Cycle Assessment (LCA) is an efficient environmental management tool that is used to consider the whole waste management systems to predict their probable environmental burdens [viii].

The present study focuses on the chemical and physical characterization of the MSW being generated in Ravi Town, Lahore and the quantification of associated air emissions and level of GHG contribution along with the subsequent global warming potential (GWP) using IWM-2 Model.

II. MATERIALS AND METHODS

A. Sampling & Data Collection

Samples were collected from waste collection vehicles of each union council of the Ravi Town, Lahore. Sample collection was carried out in accordance to ASTM - D5231-92 standard during October, 2012 Late Summer (Season 1) and December, 2012 Winter (Season 2).

B. Physical Characterization of Municipal Solid Waste

The physical characterization of the MSW into kitchen waste, paper, plastic, metals, glass, wood and textile was conducted in the solid waste laboratory of the College of Earth and Environmental Sciences, University of the Punjab, Lahore.

C. Characterization of Municipal Solid Waste

1) Proximate Analysis

The proximate analysis, involving the determination of moisture content, volatile matter, and ash content was carried out in accordance to ASTM D 3173-11, ASTM D3175-11 and ASTM D3174-11 respectively.

2) UltimateAnalysis

The ultimate analysis to determine the percentage of carbon, hydrogen, nitrogen, oxygen and sulphur

contents in waste components was performed using formula [ix]. The results of the ultimate analysis were used to characterize the chemical composition of the municipal solid waste.

3) Energy Content

The gross calorific value of each component of the waste was calculated in accordance to ASTM D5468-02 using LECO AC 500 Auto Bomb Calorimeter.

D. Estimation of Air Emissions and Global Warming Potential

The estimation of gaseous emissions and global warming potential associated with the greenhouse gases emitted from the waste management system were calculated using IWM-2: A Life Cycle Inventory Model for Integrated Waste Management.

E. Statistical Analyses

The Statistical Package for Social Sciences (SPSS) 16.0 was used for the data analyses.

III. Results and Discussion

The main component of MSW of the Ravi Town during Season 1 and Season 2 was kitchen waste, i.e. 29.19% and 59.66% respectively (Table I).

TABLE I
PHYSICAL COMPOSITION OF MSW OF THE RAVI TOWN DURING SEASON 1 AND SEASON 2

Waste Component	Composition (%)	
	Season 1	Season 2
Kitchen Waste	29.19	59.66
Metals	1.17	0
Glass	0.44	0
Paper	1.99	8.76944
Textile	4.03	10.85754
Plastic	21.11	10.63164
Wood	15.42	10.08138
Animal Waste	26.61	0
Total	100	100

A similar finding for waste composition was reported by [x] for Lahore waste. This high organic fraction in the waste is due to lifestyle of the local households. The physical composition of the waste is the major factor that governs the greenhouse gases generation during the waste management [xi]. A significant level of methane could be generated by anaerobic decomposition of this organic fraction of waste at dumpsites/ uncontrolled landfill sites. Furthermore, this substantial organic portion of the waste may possesses threat to human health as it will attract rodents and other disease vectors to the collection and dumping sites [xii]. Table I shows the detail physical composition of MSW of the Ravi Town.

TABLE II
WEIGHT CONTRIBUTION OF EACH ELEMENT IN THE SOLID WASTE OF RAVI TOWN DURING SEASON 1 AND SEASON 2

Element	Atomic weight	Season 1	Season 2
		Weight (g)	Weight (g)
C	12	217.52	187.59
S	32	1.778	1.343
H	1	31.72	29.13
N	14	6.611	7.11
O	16	341.76	274.82

Approximate Chemical formula obtained from the calculation in Table II for Season 1 is $C_{18}H_{31}NS0_{21}$ and for Season 2 is $C_{15}H_{29}NS0_{17}$ [ix]. The moisture content, volatile combustible matter, fixed carbon and ash content of the MSW of the Ravi Town is shown in Table III.

The gross calorific value (Kcal/ kg) for MSW of the Ravi Town during Season 1 and Season 2 was determined Table IV. The highest calorific value was noted for plastic and lowest for textile fraction of the waste during both Season 1 and Season 2. During Season 2, the gross calorific value was relative more in the waste fraction of kitchen waste, plastic, textile and paper while the wood has lower calorific value as compared to the Season 1.

TABLE III
MOISTURE CONTENT (MC %), VOLATILE COMBUSTIBLE MATTER (VCM %), FIXED CARBON (FC %) AND ASH CONTENT (%) OF MSW OF THE RAVI TOWN DURING SEASON 1 AND SEASON 2

Component	MC (%)		VCM (%)		FC (%)		Ash Content (%)	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
Kitchen Waste	80.22	70.37	24.8	5.32	10.55	31.24	28.55	13.22
Paper	10.82	45.56	13.42	18.55	20.78	21.35	4.65	19.5
Textile	7.91	4.5	31.22	39.41	3.43	5.11	4.56	15.75
Plastic	7.3	1.7	12	35.31	21.68	9.43	22.87	16.33
Wood	8.3	0.9	16.33	3.44	27.15	34.78	2.51	37.43
Animal Waste	86.45	0	14.66	0	9.21	0	40.4	0

In present study, the MSW is disposed off in low lying outskirt area of the city, i.e. Saggian dump site without any landfill gas collection system, landfill gas monitoring system, leachate collection system, base liner, compaction, and covering of wastes. Therefore, the air pollutants are directly released into environment. Similarly, no proper air emission management strategies have been opted to prevent the release of gases during the collection of MSW of Ravi Town. Consequently, the air pollution has turn out to be a major threat to human health and environment [xiii].

TABLE IV
GROSS CALORIFIC VALUES (KCAL/ KG) FOR MSW OF THE RAVI TOWN DURING SEASON 1 AND SEASON 2

Component	Season 1	Season 2
Kitchen Waste	3285	3756
Paper	3462	3617
Textile	2865	3256
Plastic	6021	6229
Wood	3687	3546
Animal Waste	3564	0

Air emissions results indicates that the biggest air pollutant being emitted from MSW management of the Ravi Town waste is CO_2 Table V. The extent of remaining air pollutants being emitted from MSW collection and disposal at dump site are represented in Table V.

TABLE V
AIR EMISSIONS ASSOCIATED WITH MSW MANAGEMENT OF THE RAVI TOWN

Emission Parameter	Units	Collection	Landfill	Total
Particulates	Kg	20,300.122	Zero	20,300.122
CO	Kg	3,610.061	311.960	3,922.020
CO_2	kg	18,887,829.740	22,060,042.126	40,947,871.866
CH_4	kg	51,201.427	9,804,518.626	9,855,720.054
NOx	kg	44,972.033	Zero	44,972.033
N_2O	kg	269.320	Zero	269.320
SOx	kg	139,653.253	Zero	139,653.253
HCl	kg	2,900.168	1,622.190	4,522.358
HF	kg	306.365	324.438	630.804
H_2S	kg	Zero	4,991.355	4,991.355
Total HC	kg	Zero	49,913.550	49,913.550
Chlorinated HC	kg	1	873.487	873.488
Ammonia	kg	61.858	Zero	61.858
Cadmium	kg	0.698	0.140	0.838
Lead	kg	7.344	0.127	7.471
Manganese	kg	2.749	Zero	2.749
Mercury	kg	0.393	0.01	0.403
Nickel	kg	53.662	Zero	53.662
Zinc	kg	7.408	1.872	9.28

In terms of magnitude, among the greenhouse gases calculated for the MSW of Ravi Town, the carbon dioxide (CO_2) is the principle greenhouse gas released into environment Table VI. In total 40,947,871.866 kg of CO_2 is being emitted into air through collection and landfilling of MSW of the Ravi Town. The second biggest greenhouse gas released is methane (CH_4) with combine 9,855,720.054 kg emission from collection and landfill activities. The nitrous oxide (N_2O) emission is lowest with 269.320 kg being released during collection process and no N_2O emission is associated with landfill. The EPA, 2002 and IPCC, 2006 reported insignificant N_2O emission at the landfill so its contribution in landfill greenhouse gases studies was also discounted [xi].

TABLE VI
GREENHOUSE GASES EMISSIONS AND ASSOCIATED GLOBAL WARMING POTENTIAL OF MSW OF THE RAVI TOWN

	Units	Collection	Landfill	Total
CO_2	Kg	18,887,829.740	22,060,042.126	40,947,871.866
CH_4	Kg	51,201.427	9,804,518.626	9,855,720.054
N_2O	kg	269.320	Zero	269.320
GWP	kg	20,046,548.955	227,954,933.282	248,001,482.237

The CH_4 has the global warming potential (GWP) of 25 [xiv]. Therefore, despite of relative lower CH_4 emission, the global warming contribution of CH_4 is greater than that of CO_2. Similarly, the GWP of N_2O is 298 [xiv] that manifold amplifies the N_2O contribution in global warming. The total GWP calculated for this study is 248,001,482.237 kg, 20,046,548.955 kg associated with collection of MSW of Ravi Town and 227,954,933.282 kg associated with landfill activities.

This significant contribution in global warming by MSW management strategies in Ravi Town, Lahore may be reduced through biogasification [vii]. Almost 56% biomass in Season 1 and 60% in Season 2 can undergo effective biogasification. This would not only reduce greenhouse gases emissions but also produces energy and compost, a suitable soil conditioner with economic returns [xv].

IV. CONCLUSIONS

Significant GHG emissions are associated with the collection and disposal of MSW of Ravi Town at Saggian dump site. Presently, a total 40,947,871.866 kg of CO_2, 9,855,720.054 kg of CH_4, and 269.320 kg of N_20 is released into environment with a combine GWP of 248,001,482.237 kg for MSWM of Ravi Town. As MSW contains 56% biomass in Season 1 and 60% in Season 2 that favors the effective biogasification of the MSW that would subsequently reduce the global warming potential. Furthermore, along with reduction

of substantial greenhouse gases emissions the production energy and compost would also assist the MSWM with economic returns.

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Effect of Fines Content on Dry and Saturated Indirect Tensile Strength of Hot Mix Asphalt Mixtures

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Abstract-Fines and coarse aggregates play vital role in achieving strength properties of hot mix asphalt (HMA) mixtures. ASTM D 3515 recommends nine types of gradations combinations to be used for HMA with variable fractions of fines. In this research the effect of fines in these nine gradations of HMA were evaluated. HMA with variable fines contents were prepared in laboratory using gyratory compactor. The indirect tensile strength using Universal Testing Machine (UTM HYD-25-II) of original and moisture conditioned HMA samples were determined. Tensile strength ratio (TSR) of the HMA samples was also evaluated. It has been observed that with the increase in the fines content the strength and TSR of HMA samples initially increase then it decrease. The HMA mixes having low plastic fines (PI = 6) should not be exceeded beyond 10 % in order to achieve optimum strength.

Keywords-Hot Mix Asphalts, Fines, Indirect Tensile Strength, Tensile Strength Ratio, Moisture Conditioning

I. INTRODUCTION

The design and performance of hot mix asphalt (HMA) is greatly influenced by the nature and amount of the fines in the mix. The properties of fine particles of dense-graded HMA greatly change according to their source. The fines are very important part of HMA and play major role for toughening and stiffening of asphalt binder. The stiffening and toughening effects of fine particles have been documented in detail in the literature. Fine particles are also important for stripping and moisture damage considerations. Fines also play a significant role in HMA mixtures. The high load bearing capacity and strength of HMA is due to aggregate framework developed by intra particles contact and their interlocking. Well graded dense HMA consists of successively different size particles i.e. large particles framework is filled by small particles. The coarse aggregates framework is filled by sand and then mineral fillers. At some stage the small particles loose contact with other particles and becomes suspended in the asphalt binder. These small particles do not have the intra particle contact of larger particles [i]. Detailed studies of the difference between rounded and crushed coarse aggregates in HMA were done in the past by different researchers. The replacement of the rounded aggregates by crushed fine aggregates improved mixture properties increased stability reduced rutting, improved water resistance [ii].

The stripping resistance of asphalt mixtures is evaluated by the decrease in the loss of the indirect tensile strength (ITS) in which cylindrical specimens are subjected to compressive loads. These loads act parallel to the vertical diametric plane by using the Marshall loading equipment. This type of loading produces a relatively uniform tensile stress, which acts perpendicular to the applied load plane, and the specimen usually fails by splitting along with the loaded plane [iii].

Moisture damage is a primaryway of distress in HMA commonly known as stripping. Stripping speeds up structural degradation of the mixtures accompanied by cracking and plastic deformation. The decrease of the adhesion between aggregates and asphalt in the presence of water and the deterioration of the asphalt due to cohesive failure within the asphalt binder itself has been known as two principal driving mechanisms of moisture damage that may results in premature distresses such as raveling and fatigue cracking [iv].

Many highway agencies have been experiencing untimely failures that lessen the performance and servicelife of the pavements.However, the reasons of the increase inpavement distress because of moisture susceptibility havenot been actually identi?ed. Researchers suggest that change of asphalt binders, decrease of asphalt bindercontent to satisfy rutting

associated with increase in traffic, change in amount of fines, and poor quality control are the main reasons for increased water sensitivity problems [v-vi].

Maintenance of roads in Pakistan costs annually high percentageof the total road construction costs or in other words, in the future, maintenance cost will become equal to the construction cost of new roads. Roads in Pakistan usually show excessive failures at an early stage of pavement life. The majority of the road network in Pakistan consists of asphalt concrete (AC) pavements. Asphaltic mixtures are composed of bitumen, aggregates, sand and filler particles. In asphaltic pavements, which are continuously exposed to moisture infiltration, separation of the aggregates from the mix is a major problem. The continuous moisture in a pavement induces weakening while traffic load causes the mechanical damage which automatically results in a progressive dislodgement of aggregates. Therefore damaged spots are seen on highways and urban roads, after the seasonal rains, causing strippingdue to the properties of local aggregates (coarse and fine). The existing practices of asphalt mix design technology of Pakistan need up gradation considering local materials, climate and traffic loading conditions existent in Pakistan.The main objective of this research is to evaluate the effect of fines content on dry and moisture conditioned indirect tensile strength of HMA mixtures used in Pakistan.

METHODOLOGY

Following methodology was adopted to achieve the research objectives by consulting references [vii-xiii].

Review of literature to identify most of the gradations used in America, Middle East and Pakistan for the preparation of bituminous mixtures (ASTM D3515) [vii,viii]

Selection of fine aggregates, coarse aggregates and bitumen to be used in HMA mixtures.

Characterization of fine aggregates through specific gravity test (ASTM C 128), grain size distribution test (ASTM D 6913), atterberg limits test (ASTM D4318), sand equivalenttest (ASTM D 2419), sodium sulphate soundness test (ASTM C 88) etc.

Characterization of coarse aggregates through sodium sulphate soundness test (ASTM C 88), Los Angeles abrasion test (ASTM C 131), flaky and elongation test (ASTM D 4791) etc.

Characterization of bitumen through penetration test (ASTM D 5), ductility test (ASTM D 113), flash and fire point test (ASTM D 92), softening point test (ASTM D 36) etc.

Preparation of different HMA mixtures in the laboratory using gyratory compactor (ASTM D 6925) with varying percentage of fines of same physical properties.

Evaluation of indirect tensile strength (ASTM D 6931) of HMA mixtures using servo-hydraulic universal testing machine.

Evaluation of moisture susceptibility of HMA mixtures (ASTM D4867).

Data Analysis include indirect tensile strength and tensile strength ratio calculation

The Indirect tensile strength is computed using equation (1).

$$S_t = \frac{2000*P}{\pi*t*D} \quad (1)$$

S_t= Indirect Tensile (IDT) strength, kPa
P = Maximum load, N
t = Specimen height, mm
D = Specimen diameter, mm
Tensile strength ratio (TSR) is computed using equation (2)

$$TSR = \left(\frac{S_{tm}}{S_{td}}\right) \quad (2)$$

TSR = tensile strength ratio
S_{tm}= average tensile strength of the moisture-conditioned sample, kPa
S_{td} = average tensile strength of the dry sample, kPa.

RESULTS AND DISCUSSIONS

Table I presents gradations of bituminous mixtures with respect to the grain size of aggregates and percentage of bitumen, as recommended by ASTM D3515 [vii].

It can be seen from Table I that in different mix designations (D-1 to D-9) fines material (75µm, No. 200) varies from 0 to 20%, cumulative percentage passing. Based on guidelines of ASTM D3515, bituminous mixtures reported inthe parenthesis of Table I are prepared in the laboratory with varying percentage of fines. These mixes are batched by weight.

Gradations D1 to D5 are more capable of taking heavy loads due to more percentage of coarse aggregates. While gradations D6 to D9 are more pronounced for surfacing due to presence to fines as major content.

Ubhanshah aggregate and bitumen obtained from national refinery and attock refinery were used in the preparation of bituminous mixtures. Table II (a) & (b) presents the physical characteristics of fines (sand, silt/clay). The silt/clays are identified as low plastic and sands are identified as medium to fine sands.

TABLE I
COMPOSITION OF BITUMINIOUS MIXTURES AS PER ASTM D3515
(COMPOSITION OF BITUMINIOUS MIXTURES PREPARED IN THE LABORTARY)

Sieve Size	Mix Designation								
	D-1	D-2	D-3	D-4	D-5	D-6	D-7	D-8	D-9
	Cumulative Percentage Passing %								
63-mm	100 (100)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)
50-mm	90 to 100 (95)	100 (100)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)
37.5-mm	… (…)	90 to 100 (95)	100 (100)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)
25.0-mm	60 to 80 (70)	… (…)	90 to 100 (97)	100 (100)	… (…)	… (…)	… (…)	… (…)	… (…)
19.0-mm	… (…)	56 to 80 (70)	… (…)	90 to 100 (95)	100 (100)	… (…)	… (…)	… (…)	… (…)
12.5-mm	35 to 65 (50)	… (…)	56 to 80 (75)	… (…)	90 to 100 (95)	100 (100)	… (…)	… (…)	… (…)
9.5-mm	… (…)	… (…)	… (…)	56 to 80 (63)	… (…)	90 to 100 (95)	100 (100)	… (…)	… (…)
4.75-mm (No. 4)	17 to 47 (24 to 27)	23 to 53 (30)	29 to 59 (37)	35 to 65 (42)	44 to 74 (59)	55 to 85 (70 to 71)	80 to 100 (80 to 81)	… (…)	100 (100)
2.36-mm (No. 8)	10 to 36 (20)	15 to 41 (25)	19 to 45 (30)	23 to 49 (30)	28 to 58 (43)	32 to 67 (60)	65 to 100 (67)	… (…)	95 to 100 (95)
1.18-mm (No. 16)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)	40 to 80 (65)	… (…)	85 to 100 (85)
600-µm (No. 30)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)	25 to 65 (45)	… (…)	70 to 95 (70)
300-µm (No. 50)	3 to 15 (10)	4 to 16 (10)	5 to 17 (15)	5 to 19 (8)	5 to 21 (13)	7 to 23 (20)	7 to 40 (25)	… (…)	45 to 75 (56 to 65)
150-µm (No. 100)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)	3 to 20 (15)	… (…)	20 to 40 (40)
75-µm (No. 200)	0 to 5 (1 to 3)	0 to 6 (3)	1 to 7 (4)	2 to 8 (5)	2 to 10 (6)	2 to 10 (7 to 8)	2 to 10 (9 to 10)	… (…)	9 to 20 (11 to 20)
	Bitumen, Weight % of Total Mixture								
	2 to 7 (4)	3 to 8 (4)	3 to 9 (4)	4 to 10 (4)	4 to 11 (4)	5 to 12 (5)	6 to 12 (6)	7 to 12 (…)	8 to 12 (8)

TABLE II (a)
FINE AGGREGATES (SAND) TEST RESULTS

Sr. No	Tests Description	Results
1	Uncompacted voids [viii]	
	ϒmin (gm / cm3)	1.41
	ϒmax (gm / cm3)	1.64
2	Sand equivalent (%) [ix]	84
3	Specific Gravity [x]	2.68

TABLE II (b)
FINE AGGREGATE (SILT/CLAY) TEST RESULTS

Sr. No	Tests Description	Results
1	Liquid Limit (%) [xi]	22
2	Plasticity Index (%) [xi]	6
3	Clay (%) [xii]	8-10
4	Silt (%) [xii]	90-92

Table III present results of physical characteristics of coarse aggregates. The results show the physical characteristics of *ubhanshah aggregate* falls well within the acceptable typical range of ASTM Specifications.

Table IV shows summary of bitumen physical properties determined from different tests, both samples of bitumen falls well within the typical acceptable range of bitumen samples as recommended by ASTM Specifications.

Aggregates and bitumen were mixed mechanically (ASTM D 6925) and compacted using gyratory compactor (Fig. 1). Table V presents test conditions used during compaction.

One set of the compacted samples was tested using universal testing machine (Fig. 2). Specimens were loaded diametrically, in which cylindrical specimens were subjected to compressive loads. These loads act parallel to the vertical diametric plane. This type of loading produces a relatively uniform tensile stress, which acts perpendicular to the applied load plane, and the specimen usually fails by splitting along with the loaded plane (Fig. 3). Table VI shows test conditions adopted in UTM for determination of indirect tensile strength. This set of samples is designated as “dry” in legends.

Other set of samples was placed in moisture conditioning bath (Fig. 4) for 24 hours at temperature of 60°C ± 1°C as per ASTM D 4867. The temperature of moisture conditioned samples is then adjusted by soaking in a water bath for 1 h at 25 ± 1°C. The elapsed time from removal of test specimen from the water bath to the IDT strength testing using UTM shall not exceed 2 min [xiii]. The conditioned tested samples were designated as "saturated" in legends.

TABLE III
COARSE AGGREGATE TEST RESULTS

Sr. No	Tests Description	Test Results	Specification	Specification Limits
1	Fractured particles (%) [xiv]	100	ASTM D5821	Min. 50, Max 100
2	Flat & Elongated Particles (%) [xv]	7.48	ASTM D4791	Max. 10
3	Resistance to degradation (%) [xvi]	23.86	ASTM C131	Max. 45
4	Durability & soundness (%) [xvii]	0.42	ASTM C88	Max. 10 to 20
5	Water absorption (%) [xviii]	0.44	ASTM C127	-
6	Bulk specific gravity [xviii]	2.68	ASTM C127	-
7	Apparent specific gravity [xviii]	2.71	ASTM C127	-
8	Effective specific gravity [xviii]	2.7	ASTM C127	-
9	Unit weight loose (gm/cm^3)	1.32	-	-
10	Unit weight rodded (gm/cm^3)	1.54	-	-

TABLE IV
BITUMEN PHYSICAL CHARACTERISTICS

Bitumen Source	Tests Description	Test Results	Penetration Grade	Specification	Specification Limits
National Refinery Limited	Penetration Test Result (0.1mm) [xix]	47	40-50	ASTM D5	40-50
	Flash Point (°C) [xx]	335		ASTM D92	Min. 230
	Fire Point (°C) [xx]	372		ASTM D92	Min. 230
	Ductility (cm) [xxi]	121		ASTM D113	Min. 100
	Softening Point (°C) [xxii]	57.1		ASTM D36	Min 48
	Solubility (%) [xxiii]	99.91		ASTM D2042	Min. 99
Attock Refinery Limited	Penetration Test Result (0.1mm) [xix]	67	60-70	ASTM D5	60-70
	Flash Point (°C) [xx]	304		ASTM D92	Min. 230
	Fire Point (°C) [xx]	334		ASTM D92	Min. 230
	Ductility (cm) [xxi]	125		ASTM D113	Min. 100
	Softening Point (°C) [xxii]	48.9		ASTM D36	Min 48
	Solubility (%) [xxiii]	99.86		ASTM D2042	Min. 99

TABLE V
GYRATORY COMACTOR TEST CONDITION [XIV]

Mass of specimen (grams)	2500 to 2700	ASTM D6925
Vertical Pressure (kPa)	600 ± 18	ASTM D6925
Number of revolutions	205	ASTM D6925

TABLE VI
UTM TEST CONDITIONS [XXV]

Sample thickness (mm)	50.8	ASTM D6931
Sample diameter (mm)	101.6	ASTM D6931
Test temperature (°C)	25	ASTM D6931
Deformation rate (mm/min)	50 ± 5	ASTM D6931

Fig. 1. Gyratory Compactor Setup

Fig. 2. Servo Hydraulic Universal Testing Machine

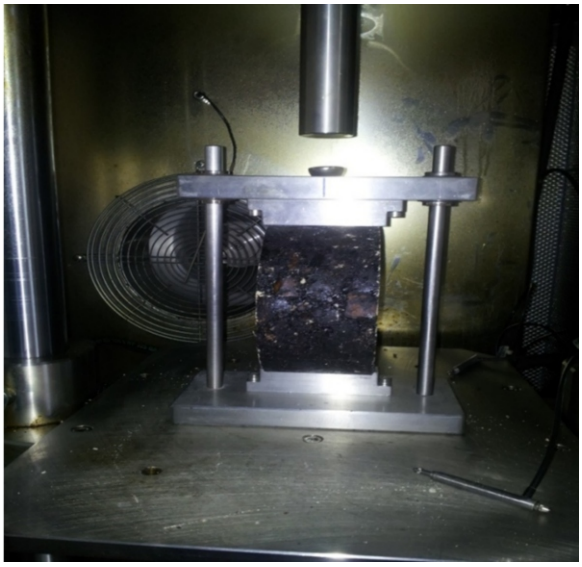

Fig. 3. Specimen Testing Machine

Fig. 5 show comparison of dry and saturated indirect tensile strength (ITS) with respect to percentage of fines (sand, silt/clay) in HMA mixtures prepared using penetration grade 40-50.

In Fig. 5, it can be seen that for dry samples indirect tensile strength of 1300kPa is obtained with 24% of sand and 1% of silt/clay in HMA mixture, which increases up to 2000kPa with 50% sand and 10% silt/clay after which it decrease. From above results it can be concluded that initial increase in IDT strength with increasing sand or silt/clay percentage is due to the mixes containing successively smaller particles such that the framework created by the larger particles is just filled by the smaller particles. Thus the coarse aggregate framework is filled by the sand-sized material and finally by the silt or clay resulting in a dense HMA mix, that is why maximum strength is also achieved with 50% sand and 10% silt/clay in the mix. After decreasing to 1000kPa the indirect tensile strength almost becomes constant above 70% sand and 17% silt/clay in the HMA mix [xxvi]. Hence increase in any further amount of fines does not affect the indirect tensile strength of the HMA mixes. For saturated samples the indirect tensile strength obtained is lesser as compared to that of dry samples but overall trend remains the same. Saturated strength is lesser as compared to dry strength, due to the loss of adhesion (stripping) or loss of cohesion (i.e. softening of asphalt that weakens the bond between asphalt and aggregate) due to the intrusion of water into the HMA mix. The stripping of asphalt from the aggregates results in the reduction of strength of asphalt concrete mixture

[xxvii].

Fig. 4. Moisture Conditioning Bath

Fig. 5 also shows variation of tensile strength ratio (TSR) by the addition of fines (sand, silt/clay) using penetration grade 40-50. In Fig. 5 it can be clearly observed that tensile strength ratio of 0.80 is achieved for 24% of sand and 1% of silt/clay and then there is an increase in TSR with increasing percentage of sand in the mix up to 0.92 at 50% sand and 10% silt/clay after which the TSR shows a decreasing trend. TSR is used for predicting the moisture susceptibility of the mixtures. According to previous researches a TSR of 0.8 or above has typically been utilized as a minimum acceptable value for hot mix asphalt. Mixtures with tensile strength ratios less than 0.8 are moisture susceptible and mixtures with ratios greater than 0.8 are relatively resistant to moisture damage [xxviii, xxix]. After moisture conditioning approximately 20% reduction in strength is observed at 24% of sand and 1% of silt/clay in HMA mix which improves to 7% at 50% of sand and 10% silt/clay in HMA mix. Since the aggregates formwork is strongly interlocked with coarse and fine aggregates, it is difficult for moisture to percolate through the mix. The reduction in strength exceeds 25% at 70% sand and 17% silt/clayin the HMA mix because there is no stronger aggregate-bitumen bond due to presence of larger amount of fines in HMA mix [xxx].

Fig. 6 show comparison of dry and saturated indirect tensile strength with respect to percentage of fines (sand, silt/clay) in HMA mixtures prepared using penetration grade 60-70. In Fig. 6 it can be seen that for dry samples initial indirect tensile strength at 24% of sand and 1% of silt/clay in HMA mix is near 900kPa, which is lesser as compared to indirect tensile strength obtained using penetration grade 40-50 as in Fig. 5. Since 40-50 is harder grade as compared to 60-70 therefore its strength is also relatively higher as compared to 60-70 which is softer grade. Indirect tensile strength increases up to 1400kPa for 50% of sand and 10% silt/clay in HMA mix after which it decreases to 900kPa at 70% sand and 17% silt/clay in the HMA mix. For saturated samples the indirect tensile strength obtained is lesser as compared to that of dry samples but overall trend remains the same.

Fig. 6 also shows variation of tensile strength ratio (TSR) by the addition of fines (sand, silt/clay) using penetration grade 60-70. In Fig. 6 it can be clearly observed that tensile strength ratio of 0.78 is achieved for 24% of sand and 1% of silt/clay and then there is an increase in TSR with increasing percentage of sand in the mix up to 0.92 at 50% sand and 10% silt/clay after which the TSR shows a decreasing trend. After moisture conditioning approximately 23% reduction in strength is observed at 24% of sand and 1% of silt/clay in HMA mix which improves to 8% at 50% of sand and 10% silt/clay in HMA mix. Since the aggregates formwork is strongly interlocked with coarse and fine aggregates, it is difficult for moisture to percolate through the mix. The reduction in strength exceeds 23% at 70% sand and 17% silt/clay in the HMA mix because there is no stronger aggregate-bitumen bond due to presence of larger amount of fines in HMA mix.

CONCLUSIONS

Following conclusions can be drawn from the findings of the research:

1. Bitumen penetration grade 40-50 shows more indirect tensile strength than grade 60-70 for all evaluated HMA mixes tested in original as well as moisture conditioning condition.
2. For penetration grade 40-50
   a. The indirect tensile strength of HMA gradations (D1 to D9) is 1300kPa at 25% fines (sand, silt/clay) in the mix which increase up to a limit of 2000kPa with 60% fines content then it shows decrease.

   For Penetration Grade 60-70
   b. The indirect tensile strength of HMA gradations (D1 to D9) is 900kPa at 25% fines (sand, silt/clay) in the mix which increase up to a limit of 1400kPa with 60% fines content then it shows decrease.
3. All evaluated HMA mixes showed good resistance to moisture susceptibility therefore TSR of all the nine ASTM D 3515 gradations (D1 to D9) typically range less than 1. Same has been reported in the literature also.
4. The silt/clay of low plastic characteristics (up to PI = 6) should not be used more than 10% in the HMA mixes D1 to D5 to ascertain optimum strength under heavy traffic loading.

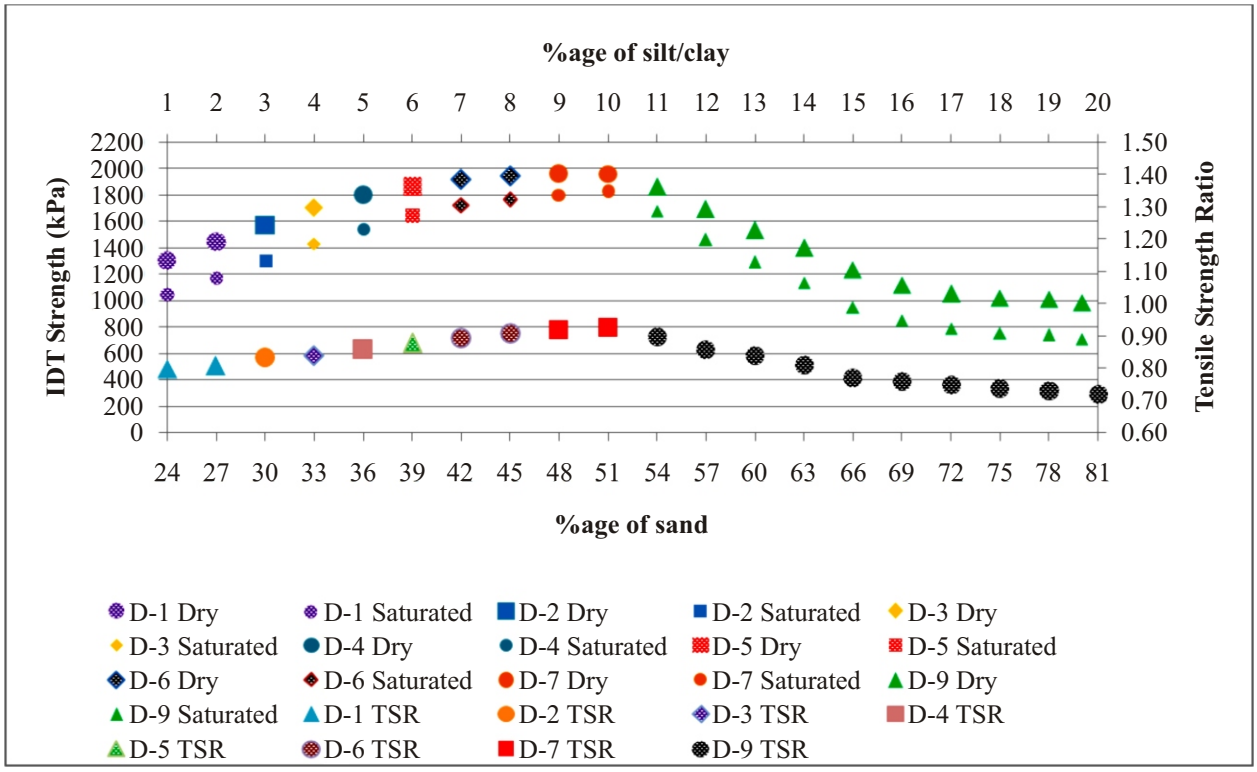

Fig. 5. ITS and TSR vs. % Fines Content (Penetration Grade 40-50)

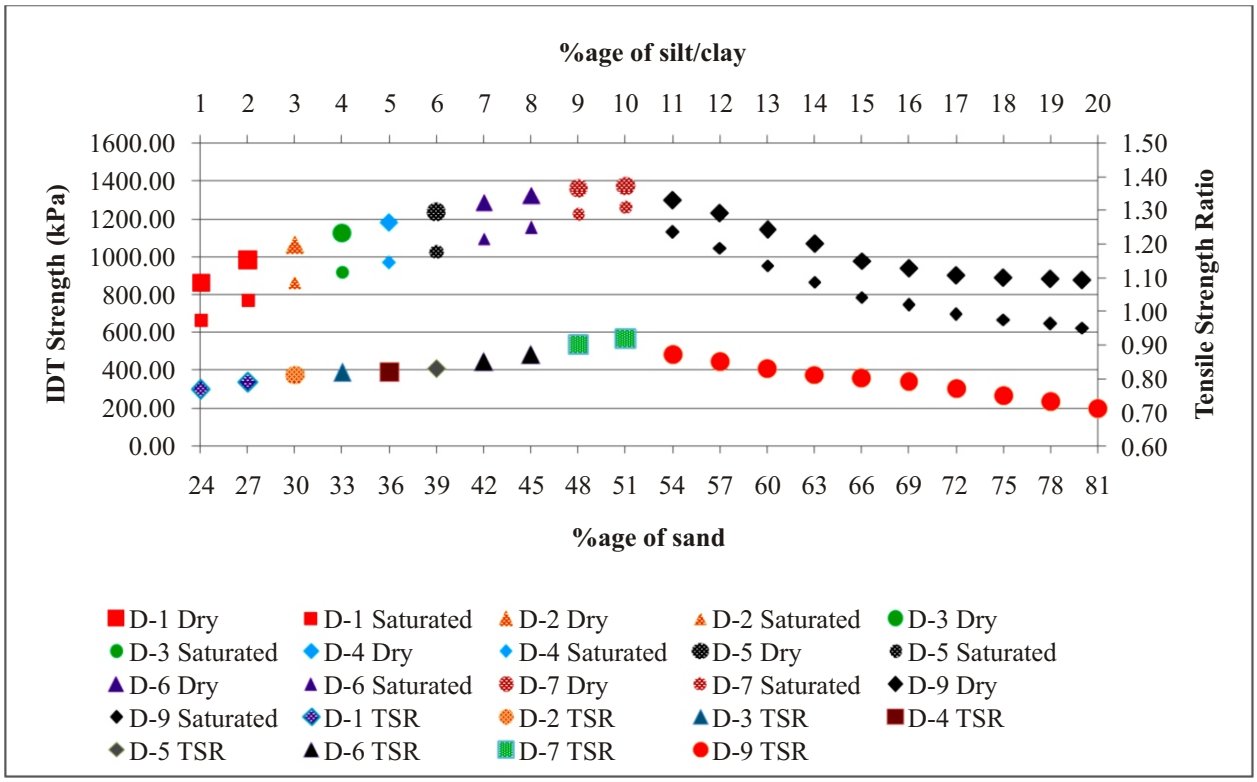

Fig. 6. ITS and TSR vs. % Fines Content (Penetration Grade 60-70)

ACKNOWLEDGMENT

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[xv] ASTM D4791-10 Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregat

[xvi] ASTM C131-03 Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

[xvii] ASTM C88-05 Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate

[xviii] ASTM C127-12 Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate

[xix] ASTM D5-06 Standard Test Method for Penetration of Bituminous Materials

[xx] ASTM D92-05 Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester

[xxi] ASTM D113-07 Standard Test Method for Ductility of Bituminous Materials

[xxii] ASTM D36-06 Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)

[xxiii]ASTM D2042- 09 Standard Test Method for Solubility of Asphalt Materials in Trichloroethylene

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Numerical Modeling of Hybrid Fiber-Reinforced Concrete (HyFRC)

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Abstract-A model for numerical simulation of mechanical response of concrete reinforced with slipping and non slipping metallic fibers in hybrid form is presented in this paper. Constitutive law used to model plain concrete behaviour is based on plasticity and damage theories, and is capable to determine localized crack opening in three dimensional (3-D) systems. Behaviour law used for slipping metallic fibers is formulated based on effective stress carried by these fibers after when concrete matrix is cracked. A continuous approach is proposed to model the effect of addition of non-slipping metallic fibers in plain concrete. This approach considers the constitutive law of concrete matrix with increased fracture energy in tension obtained experimentally in direct tension tests on Fiber Reinforced Concrete (FRC). To simulate the mechanical behaviour of hybrid fiber-reinforced concrete (HyFRC), proposed approaches to model non-slipping metallic fibers and constitutive law of plain concrete and slipping fibers are used simultaneously without any additive equation. All the parameters used by the proposed model have physical meanings and are determined through experiments or drawn from literature. The model was implemented in Finite Element (FE) Code "CASTEM" and tested on FRC prismatic notched specimens in flexure. Model prediction showed good agreement with experimental results.

Keywords-Concrete, Metallic Fibers, Hybrid, Modeling, Fracture Energy, Crack Opening

I. INTRODUCTION

Plain concrete when reinforced with randomly distributed short fibers to reduce its brittleness and increase the resistance to cracking is known as Fiber-Reinforced Concrete (FRC). Currently in practice, most of the FRCs contain only one type of fiber. It is established that failure process in concrete is of gradual and multi-scale nature. Under the application of load, the pre-existing micro-cracks in concrete grow and eventually join together to form macro- cracks. A macro-crack propagates at a stable rate until it attains conditions of unstable propagation which results in a rapid fracture. The gradual and multi-scale nature of fracture in concrete indicates that a given fiber can provide reinforcement only at one level and within a limited range of strains [i]. For optimal result therefore different types of fibers may be combined and the resulting composite is known as Hybrid Fiber-Reinforced Concrete (HyFRC).

Initiation, growth and coalescence of micro-cracks within the concrete matrix control the failure mode. The localized micro-stress fields are induced within the concrete matrix due to the geometrical anisotropy of micro-cracks which causes anisotropy and unilateral effect of damage [ii]. Fracture mechanics based modeling of concrete structure is still considered to be a challenging subject in several structural engineering laboratories of the world. The problem is approached in different ways and one of them is the fracture energy derivative methods which are closer to the fracture mechanics theory, and thanks to mesh adaptation which provides a geometrical description of the cracks. However, their implementation in commercial finite element code needs significant adaptations. As a consequence, alternatives methods have been proposed during the last decades; among them are the damage mechanics based models [iii-vii] or the softening plasticity ones [viii-ix]. Coupling between plasticity and damage is also widely used in research programs dealing with cyclic loading like seismic analyses [x-xi].

Addition of fibers in plain concrete further complicates the fracture modeling. Most of the existing numerical models of FRC deal with concrete reinforced with single type of fiber and these models can be employed successfully to predict the mechanical performance of FRC. Numerical model presented in this paper deals with plain concrete reinforced with two types of metallic fibers (slipping and non-slipping) in hybrid form. When failure of the FRC is due to pulling out of fibers, the fiber is considered as slipping fibers and when the failure of FRC is due to the fiber rupture, the fibers are characterized as non-slipping fibers [xii].

II. Model Presentation

The response of FRC containing slipping and non-slipping metallic fibers before and after cracking in direct tension is shown in Fig.1. Behaviour of FRC before cracking mainly depends upon the properties of plain concrete and the post-cracking stage is governed by the characteristics of fibers.

The effect of addition of slipping and non-slipping fibers in mono and hybrid forms on the behaviour of concrete in direct tension was studied experimentally. The curves shown in Fig. 1 were obtained from the results of this experimental study. The properties of slipping and non-slipping fibers have been reported in [xii]. The constitutive laws of plain concrete and fibers are generally combined for numerical simulation of FRC. In case of Hybrid Fiber-reinforced concrete (HyFRC) where two or more than two types of fibers are mixed, the effect of each type of fibers is considered separately to model its behaviour. Non-slipping fibers effectively control the micro-cracking mechanism in the concrete matrix and as a result, damage is diffused over large area. In this way, localization of macro-crack is delayed and fracture energy is significantly increased compared to plain concrete (Fig. 2). In this figure G_f^t represents fracture energy in tension.

In plain concrete reinforced with slipping fibers and subjected to direct tension, after micro-crack localization, an important value of post-peak stress is exhibited after drop in the stress (Fig. 1). The value of post-peak stress in FRC containing slipping fibers is greater than the value observed in control composite. Moreover, stress carrying ability after cracking is possible up to significant crack opening until the fibers are slipped from the concrete. The slipping fibers act when concrete matrix is cracked and their stress carrying ability changes with the increase of crack opening.

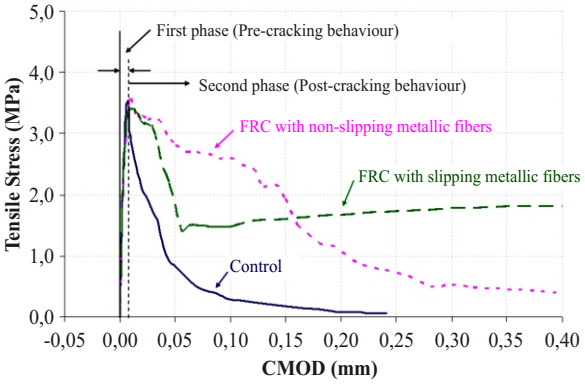


Fig. 1. Response of FRC in direct tension

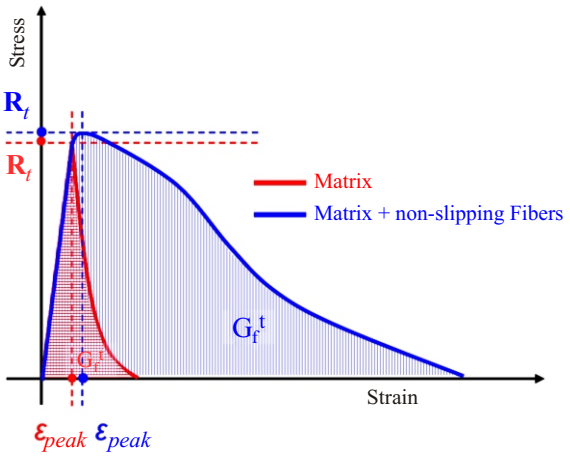


Fig. 2. Increased fracture energy in tension of concrete in the presence of non-slipping metallic fibers

2.1 Constitutive Law of Plain Concrete and Slipping Fibers

Detailed description of constitutive law of plain concrete and slipping fibers has already been published by the authors [xiii]. The model of the plain concrete supplies the crack opening and damage intensity anisotropically. Fracture energy is used explicitly by the model to regularize the post-peak behaviour and to manage the possible orthotropic crack re-closure. Constitutive law of slipping fibers considers the effective stress transferred through the crack by the slipping fibers and is computed using Equation 1.

$$\tilde{\sigma}_{f_1} = K_f \cdot w_1 \qquad (1)$$

Where K_f is the fiber rigidity; w_1 is CMOD. Equation 1 indicates that fibers act only after the localization of crack as w_1 is localized crack opening. A damage variable d_f is introduced to take into account the progressive fiber matrix de-bonding. The value of d_f varies from 0 to 1, $d_f = 1$ indicates that fiber is fully de-bonded from the concrete.

Damage theory is adopted here to model behaviour of slipping fibers rather than a plasticity formulation, because the slipping fibers buckle if they are loaded in compression and consequently, they become unable to transmit stress as illustrated in Fig. 3. If a plastic formulation is adopted to simulate their de-bonding, a compressive stress would appear in fibres during the crack re-closure process, while with a damage formulation the stress in the fiber remains positive so long as the crack opening w_1 exists, and this stress vanishes when the crack is reclosed. This approximation is more specifically representative for the fibers bridging the widely opened cracks; in this case fibers will easily buckle. At the beginning of the slipping process a plasticity formulation could also be adopted, but during this part of the behaviour the

fiber's contribution towards the global behaviour remains small compared to the residual stress in concrete and a combination of plasticity and damage would make the model complicated without significant benefits in terms of global behaviour of composite. Therefore, only the damage formulation is used in the present model.

The stress carrying capacity of the fibers taking into account the damage at matrix-fiber interface is computed using Equation 2.

$$\vec{\sigma}_{f_1} = \vec{\tilde{\sigma}}_{f_1} \cdot (1 - d_f) \quad (2)$$

The stress carried by the slipping fibers is added to the apparent stress in concrete as described in Equation 3 [xiii].

$$\vec{\sigma} = (1 - D^c)(1 - D^t) S^0 \vec{\varepsilon} + (1 - D^c) D^t \left(S^0 (\vec{\varepsilon} - \vec{\varepsilon}^{\,f}) + \vec{\sigma}_f \right) \quad (3)$$

NOMENCLATURE

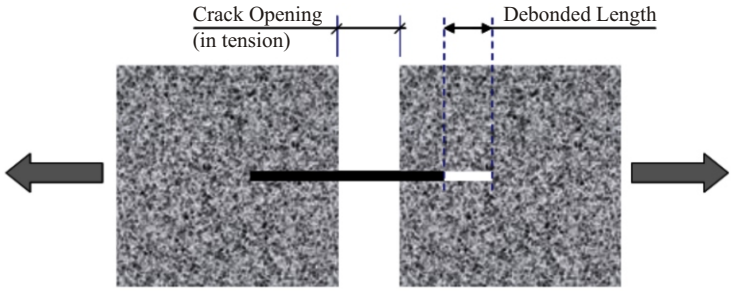
$\vec{\sigma}$ *Apparent stress*
$\vec{\tilde{\sigma}}$ *Effective stress (healthy part of the material)*
$\vec{\tilde{\sigma}}^{f}$ *Stress state in tension crack*
S^0 *Stiffness matrix of material without damage*
D^t *Tensile damage tensor*
D^c *Compressive damage tensor*
$\vec{\varepsilon}^{\,f}$ *In-elastic strain*
$\vec{\varepsilon}$ *Total strain*
$\vec{\sigma}_f$ *Effective stress carried by the fibers*
w_1 *Crack mouth opening displacement (CMOD)*

2.2 Constitutive Law of Non-Slipping Fibers

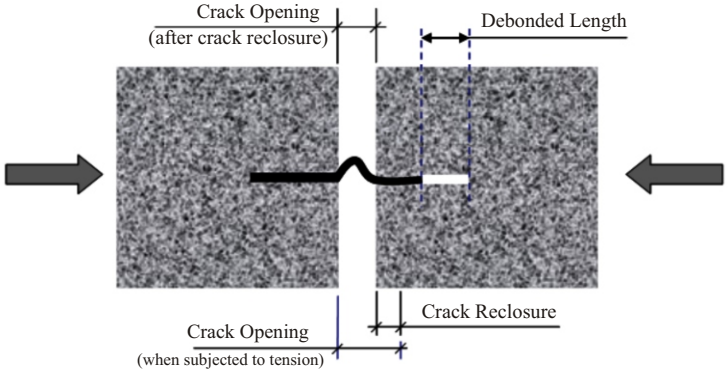
General trend of tensile stress versus CMOD curve of FRC containing non-slipping fibers shown in Fig.1 is almost similar to that of plain concrete but with greater area under the stress-strain curve which means greater fracture energy value compared to plain concrete. Constitutive behaviour law used for concrete reinforced with non-slipping fibers is of the same form as that for plain concrete but with a greater value of fracture energy in tension obtained experimentally.

2.3 Modeling of Hybrid FRC

To model the behaviour of hybrid fiber-reinforced concrete (HyFRC) containing non-slipping and slipping fibers, Equation 3 is used but the value of fracture energy in tension used for $\vec{\sigma}$ is taken similar to that for the concrete reinforced with non-slipping fibers obtained experimentally. In this approach, no additional parameters/or equations are needed to model the behaviour of HyFRC.



a) De-bonding during crack opening under tensile loading



b) Buckling of partially De-bonded fiber during crack reclosure

Fig. 3. De-bonding and buckling phenomena considered in damage model

III. Fitting of Model Parameters

Mechanical tests on concrete matrix reinforced with 20 kg/m^3 of slipping and non-slipping fibers in mono and hybrid form were performed to obtain values of different model parameters. The composition of concrete mix is given in Table I. The values of different model parameters obtained through experimentation are listed in Table II.

Model presented in this paper for HyFRC was implemented in finite element code CASTEM [xiv]. Fitting of all the model parameters was done by simulating direct tension test. Only a quarter of the specimen was simulated taking the advantage of symmetries. Computed damage pattern on FE mesh is shown in Fig. 4. In this figure, ability of the model to detect damage is obvious. Comparison of stress versus CMOD curves obtained through simulation and experiments for both mono and HyFRC is presented in Fig. 5.

TABLE I
Concrete Composition (Kg/m^3)

Cement	322
Sand	872
Gravel	967
Water	193
Admixtures	1.6
Fibers	20 for mono FRC
	20+20 for HyFRC

IV. Validation of Proposed Model

The proposed model was tested on prismatic notched specimens of size 100 x 100 x 500 mm and subjected to three point bending. Values of model parameters fitted through simulation of direct tensile tests were used in model testing. For mono and hybrid FRC, comparison of the numerical simulation results obtained in this study and experimental results [xii] for load versus deflection and load versus CMOD responses is shown in Fig. 6 to Fig. 8. In these Figures, SF stands for slipping fibers and NSF stands for non-slipping fibers. Evolution of fracture/damage on the FE mesh for each concrete is also shown in Fig.9 to Fig. 11.

From the comparison of experimental and model results for HyFRC-20+20, it is evident that the approach adopted in this study to model the behaviour of HyFRC containing slipping and non-slipping fibers gives satisfactory results. Crack localization and propagation in the finite element mesh of HyFRC-20+20 is shown in Fig.13. It is important to mention here that a positive synergy is obtained by the model; the bending strength is increased from 5kN to 7kN without additive equation. This increase is in accordance with experimental data.

TABLE II
Values of Model Parameters

Model Parameters		**Composites**			
Name	**Unit**	**Control**	**FRC-NSF20**	**FRC-SF20**	**HyFRC-20+20**
Modulus of Elasticty, E	GPa	35	34	34	34
Poisson ratio, υ	--	0.27	0.27	0.27	0.27
Tensile strength, Rt	MPa	3.5	3.5	3.0	3.5
Strain at Rt , ε^{peak^t}	--	$1.0x\frac{R_t}{E}$	$1.0x\frac{R_t}{E}$	$1.0x\frac{R_t}{E}$	$1.0x\frac{R_t}{E}$
Gf^t	MN/m	1.37 x10^{-4}	8.22x10^{-4}	1.37 x10^{-4}	8.22 x10^{-4}
Compressive strength, Rc	MPa	50	52	50	48
Strain at Rc , ε^{peak^c}	--	2.18 x10^{-3}	2.18 x10^{-3}	2.18 x10^{-3}	2.18 x10^{-3}
Drucker-Prager Parameter, δ	--	0.15	0.15	0.15	0.15
Gf^c	MN/m	1.37x10^{-2}	1.37x10^{-2}	1.37x10^{-2}	1.37x10^{-2}
K_f	MPa	--	--	11000	11000
$(w_1)_{peak}$	m	--	--	0.5x10^{-2}	0.5x10^{-2}
$(Rt_f)_1$	Mpa	--	--	1.2	1.2

SF stands for slipping fibers *NSF stands for non-slipping fibers* *20 is quantity of fibers in kg/m^3*

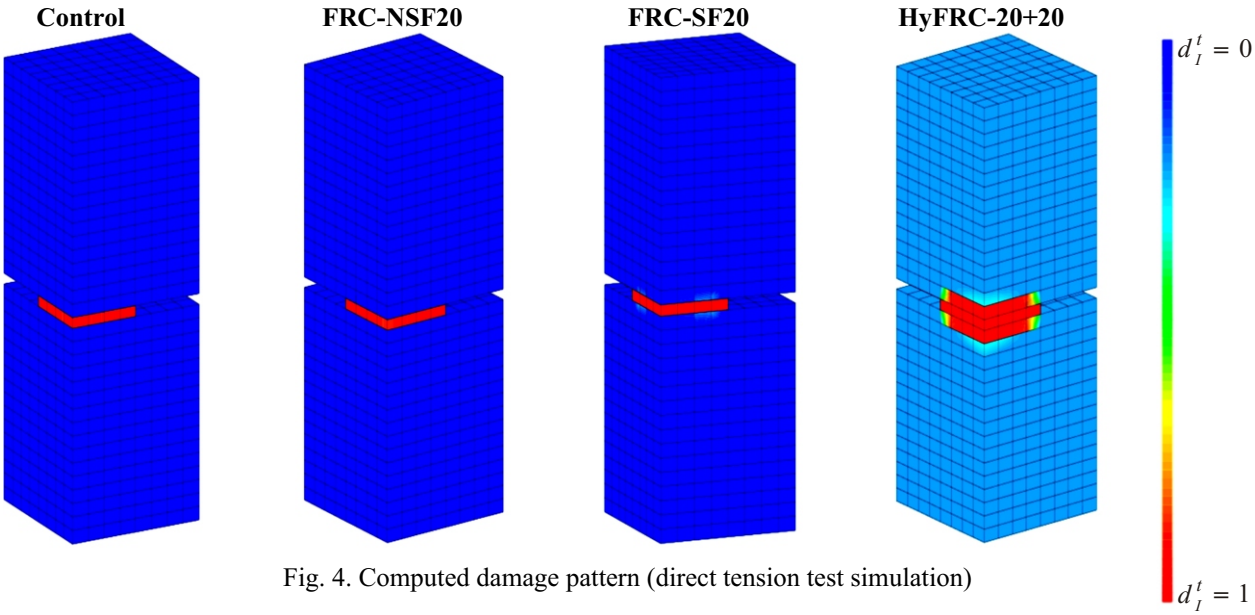


Fig. 4. Computed damage pattern (direct tension test simulation)

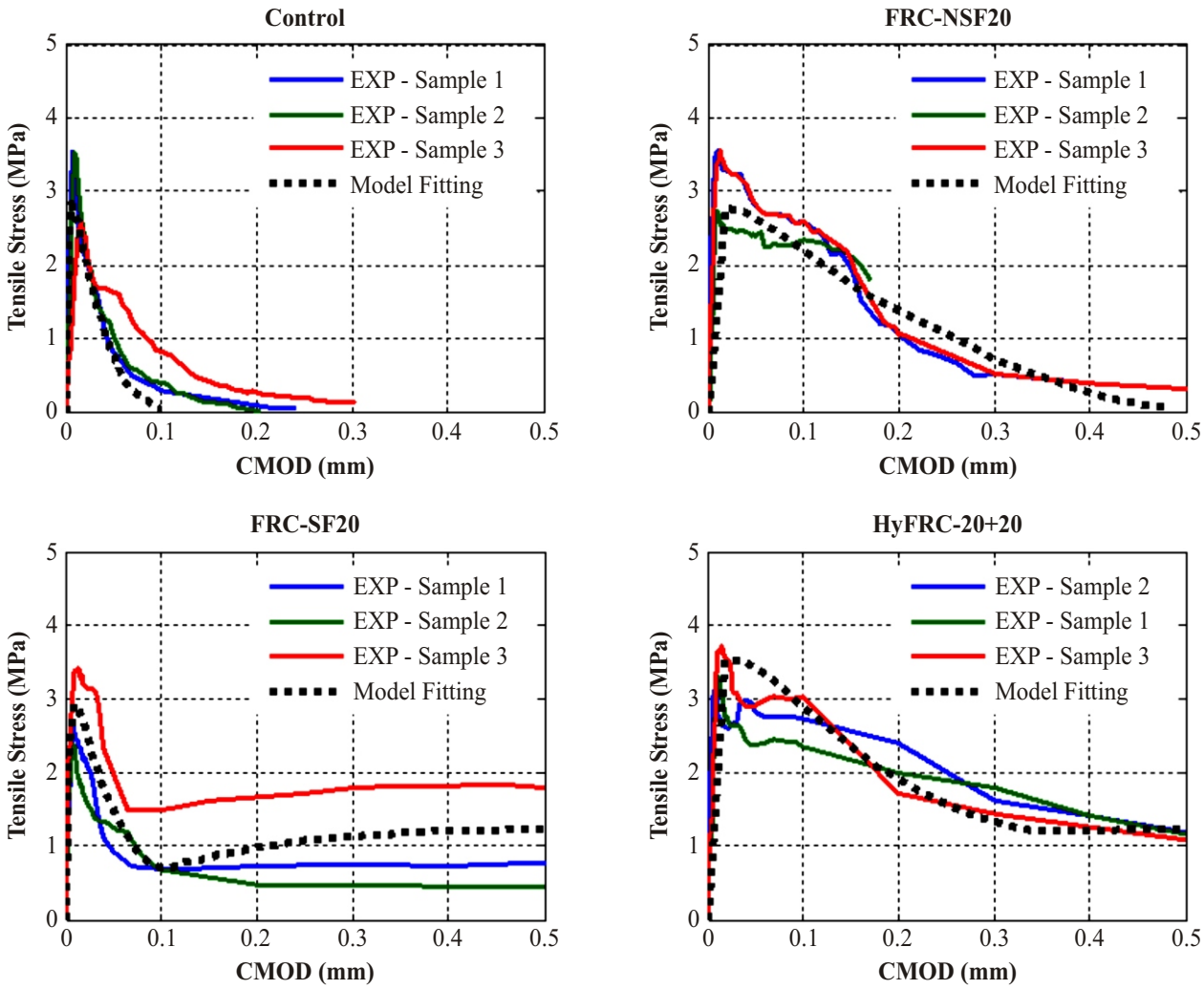


Fig. 5. Direct tension test simulation results

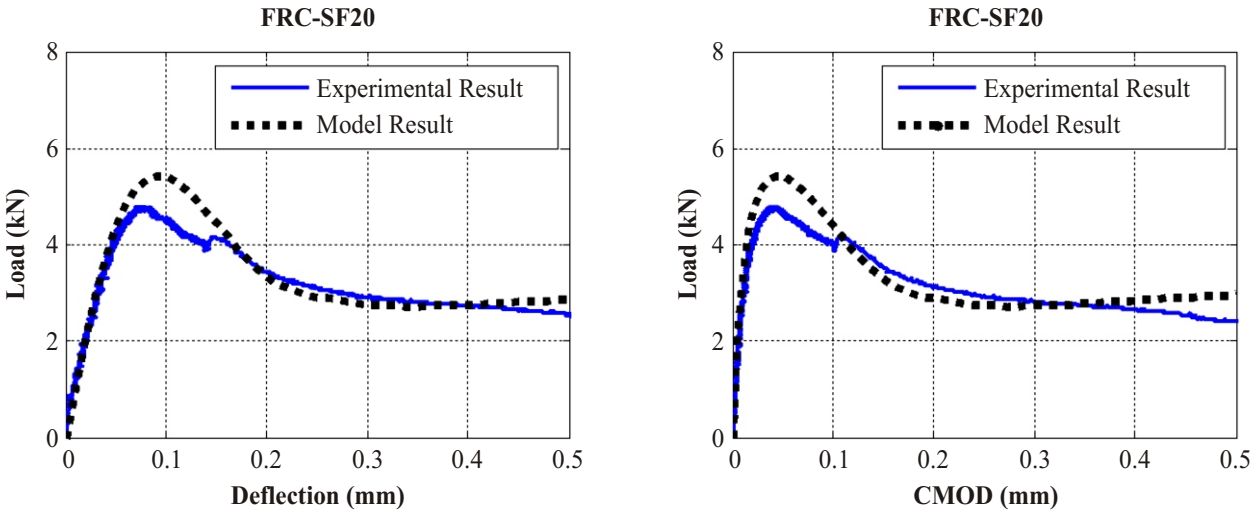


Fig. 6. Response of FRC-SF20 in 3PBT

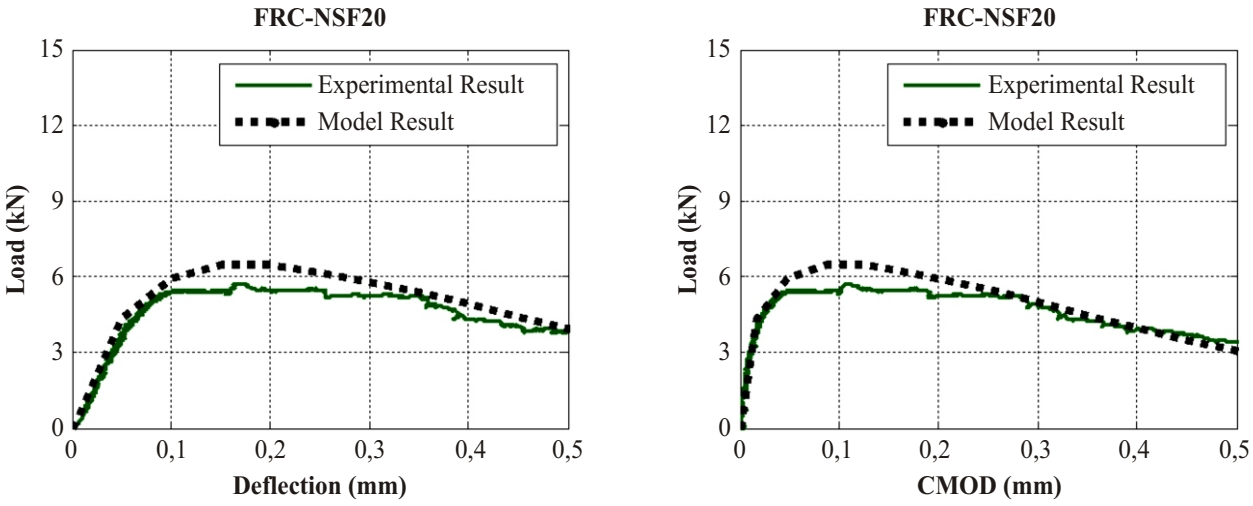


Fig. 7. Response of FRC-NSF20 in 3PBT

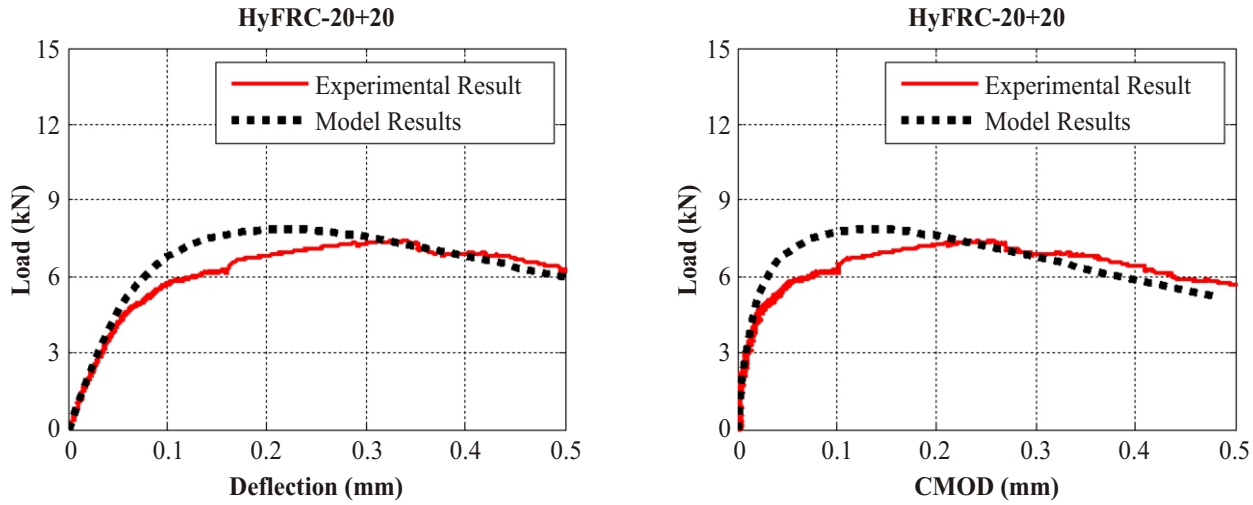
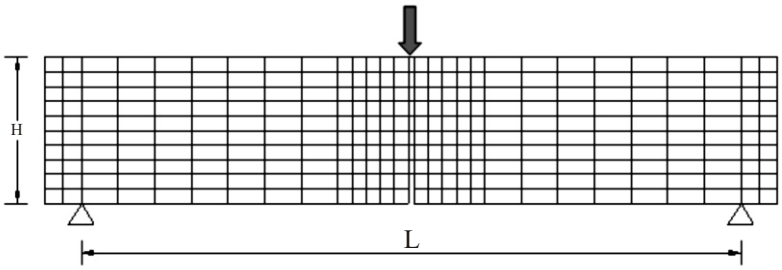
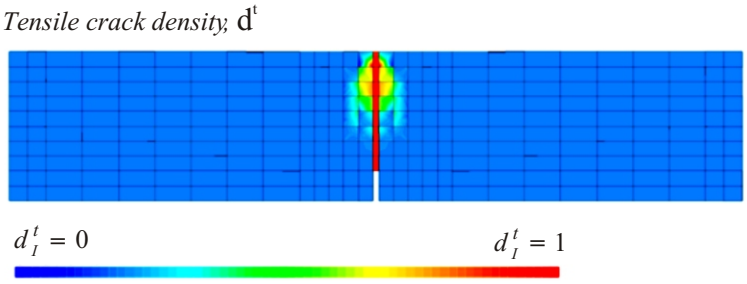


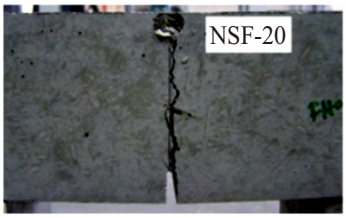
Fig. 8. Response of HyFRC-20+20 in 3PBT



a) Mesh used for three point bending test

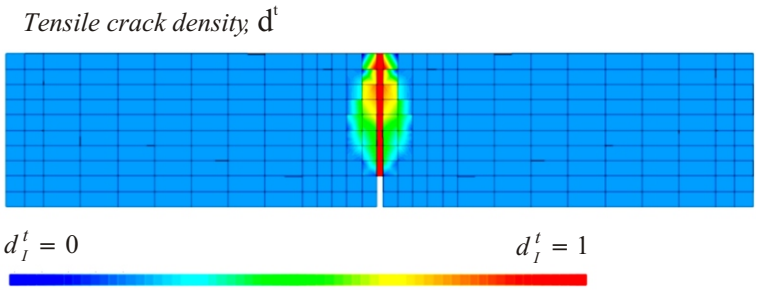


b) Damage plotted on the mesh

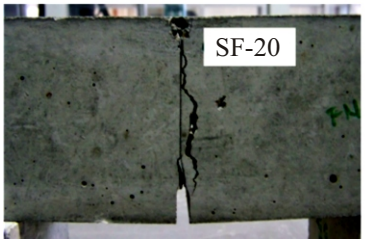


c) Experimental crack pattern

Fig. 9. Experimental crack pattern and computed damage pattern (NSF-20 in 3PBT)

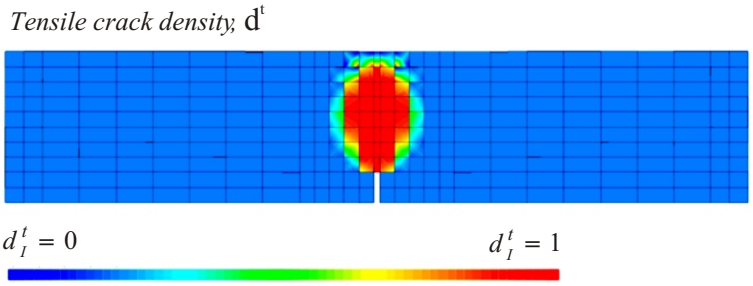


a) Damage plotted on the mesh

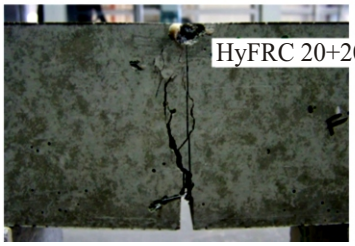


b) Experimental crack pattern

Fig. 10. Experimental crack pattern and computed damage pattern (SF-20 in 3PBT)



a) Damage plotted on the mesh



b) Experimental crack pattern

Fig. 11. Experimental crack pattern and computed damage pattern (HyFRC 20+20 in 3PBT)

V. Conclusions

A numerical model to predict behaviour of concrete reinforced with slipping and non-slipping fibers in hybrid form has been presented. The constitutive behaviour law of plain concrete matrix is based on plasticity and damage theories. The particularity of the plain concrete model lies in considering the residual stress in opened crack. Based on this particularity, behaviour law of slipping fibers was developed considering the de-bonding and buckling possibility during crack re-closure process. Modeling of non-slipping fibers considers the plain concrete behaviour law without any modification but with fracture energy in tension greater than the plain concrete to consider the additional energy required to break this type of fibers.

Testing of proposed model on notched prismatic specimens (100x100x500 mm^3) subjected to bending produced results in good agreement with experimental ones. The model is able to predict the positive synergy between the two metallic fibers without any modification or re-fitting of behaviour laws.

ACKNOWLEDGEMENT

The financial support from HEC Pakistan and technical support from Prof. Zahid A. Siddiqi and Prof. Abdul S. Shakir from Civil Engineering Department-UET Lahore Pakistan is highly acknowledged. The authors are also grateful to French Atomic Energy Commission for providing FEM code CASTEM.

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Urbanization and its Impacts on Founded Areas of Big Cities in Pakistan: Case Studies of "Ichra" and "Sanda" Areas in Lahore

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***Abstract*-**Urbanization put immense pressure on urban infrastructure and services. Burdened with unrelenting pressure, the founded areas of Lahore have now been converted into slums. Poor services, urban infrastructure and dilapidated building have made lives of the resident miserable. A significant proportion of the people is living in dangerous buildings which could be declared unfit for habitation under section 34 of Punjab Local Government Ordinance 2001 (PLGO 2001). The paper attempts to highlight situations of two founded areas of Lahore namely, Icchra and Sanda in comparison with slums areas to grade living standards of the people. Actions under PLGO 2001 and urban renewal programs are suggested to revitalize such areas.

***Keywords*-**Urbanization, Slums, Lahore City, PLGO 2001.

I. INTRODUCTION

Urban population is increasing tremendously across the World. In 2008, the world reached a momentous point when, for the first time in history, more than half of its population live in urban areas. By 2030 this number will grow to around 5 billion people, and in Africa and Asia urban populations will double between 2000 and 2030 [i]. Many of the World's large cities have been labeled as dysfunctional, mainly because of the urban degradation caused due to urbanization, congestion and growing socio-economic inequalities. Reference [ii] many Asian cities need transformation to provide both high economic growth and improved living conditions, particularly, for the poor.In line with global trend, urbanization in South Asia is also very high. Urban population of South Asia is expected to reach about one billion by the year 2030. In India urban population according to 2001 census was 285 million which is close to the joint urban population of France, UK and USA. Furthermore out of ten large cities of the world three (Mumbai, Delhi and Kolkata) are located in India. The urbanization rate in India is ranging between 3.0%-4.0%. In Mumbai, around half of the population lives in slums or on payments, lacking provision of basic services. Pakistan and Bangladesh, two prominent countries of South Asia, despite agrarian economies are experiencing high urbanization transition.

Asian cities emerged well before existence of automobile and therefore exhibit highly dense central districts as compared to American cities, which tend to be more decentralized. Asian cities are competing for infrastructure and investment opportunities but rising number of urban poor, growing inequalities, slums congestions etc. have gripped these cities. Cities compete with each other to attract global investment and try to upgrade their infrastructure to a World class status. Many contentious issues have come up that need to be resolved, particularly since these affect the living conditions of less privileged sections of the population like the urban poor and small farmers [iii]. Growing inequalities between urban poor and elite let them live in isolated, protected and sequestered neighborhoods, distant from the poor. Despite the march of these cities towards Globalization, urban poverty is among the challenging threats for South Asia, particularly for India, Pakistan and Bangladesh. This Asian Region houses 40 percent of the World's poor population [iv]. Furthermore, this region houses maximum slums and a large proportion of urban population in big cities of South Asia lives below the poverty line in shabby slums.,

Urbanization in Pakistan is very high. Much of the urbanization is due to migration. Estimates show that within a decade urban population will become half of the total population. Pakistan's current population is about one-third urban. However, that figure will rise to nearly 50% by 2025 [v]. Pakistan is prominent country of the South Asian Region. Pakistan's big cities are also facing same challenges of the Region. Urban poverty in Pakistan is increasing. Purely based upon the food intake, i.e. availability of two time meal, there are 24.2 percent poor in Pakistan. But the urban poverty added inadequate shelter also. Pakistan, India and Bangladesh house majority of the slums and preponderance of the urban population lives in slums. Estimates further suggest that about half of Karachi lives in *Katchi Abadis*. Different program initiated for improvement of the slums failed due corruption, isolation and institutional muddle. Reference [vi] In

Karachi, the first main slums and poverty reduction program was carried out during 1988 to 1993. It was failed to meet objectivity due to defective land record, corruption and non-adoption at grassroots level. Impact of recent programs could not assess due to absence or deficient monitoring and feedback.

The urban population is increasing in Pakistan. In census of 1998 it was more than 32%. Due to growing gap between demand and supply of the shelter, squatter settlements have established at heart of big cities. The share of urban population had reached at 32.5 percent (of total population) in1998 as compared to the 28.3 percent in 1981 and 17.8 percent in 1951 [vii]. At the same time the growth of the existing population also requires more housing facilities. With little financial resources, the drastic option of illegally occupying a vacant piece of land to build a rudimentary shelter is the only choice available to the people who choose to live in big cities. This phenomenon causes emergence of squatter settlement. High density living in central areas of big cities of Pakistan is high. The trend continues unrelentingly. The density of urban population has reached up to 600 persons/hectre in city centre areas with 7 to 10 persons living in one room accommodation [viii].

A. Situation of Lahore

Lahore titled as 'Paris of the Asia' [ix] is facing enormous challenges due to unrelenting urbanization, growing socio-economic inequalities and absence of the urban renewal policies. These issues are not effectively coped with city managerial expertise. Urbanization is a constant pressure to already burden urban infrastructure. Housing backlog is increasing progressively despite the unwise conversion of hectares of the agriculture land to residential areas [x]. The Socio-economic inequalities coined by British in the twentieth centuries by constructing settlement of the lords and commoner are increasing. The wide gap of Socio-economic life style between two settlements is widely filled by construction of the intermediate settlement developed by emerged middle class of that time. Onwards process of “mixing” between these regions increased with the rise of a new indigenous middle class who wanted to move out of the dirty, crowded conditions in the old city but could not afford bungalows of the type used by the British [xi]. This was then followed by a process of adaptation resulting in the formation of buildings and settlements that have been characterized in the past as a new “indigenous” urban form. But these intermediate settlements now turn into slums and now exist near around model constructed settlement. Due to influx of the migrants the founded areas of Lahore also shows a picture of slums. Absence of housing and renewal plans at lower tier, i.e. local govt. level make situation grim. Only few projects related to Wall City renewal could carry out in the city.

II. Materials and Methods

The narrated facts accentuate need to research about socio-economic and physical changes in representative areas of the Lahore. Two representative areas, namely, Sanda and Ichra selected on the basis of their featured characteristics and historical importance. Ichra and sanda both have distinguished characters and identities in overall development of Lahore. According to many historians, Lahore was founded by an ancient Rajput Colony in vicinity of Icchra. There are some grounds supporting that the old Hindu city of Lahore did not occupy exactly the site of the modern city. Tradition points the site of old Lahore to the vicinity of Ichhra - which is now a part of Lahore city - but was back then a village about three miles to the west. The name of the village was formerly *Icchra, Lahore* . Moreover, some of the oldest and most sacred Hindu shrines are to be met within this locality, namely *Bhairo ka sthain* and the *Chandrat.* Ichra therefore is an old and traditional pivot area of Lahore [xii]. It is also a budget commercial centre for people of Lahore. Sanda carries unique character due to its direct connectivity with ring road and are among the entering areas of Lahore. The situation of these two areas then match with selected slums areas to draw comparison. Methodology of the research consists upon the following focused stages

III. Analysis and Discussions

Analysis of the data comprises upon numbers of Tables and Figures but only key impact Tables and Figures shown

A. Landuses

Land uses in these areas (Sanda and Icchra) are traditionally mixed. But most of residential uses especially in Ichra are converted into commercial or commercial cum residential. Slums are in Johar Town and Shahdra are in close proximity of the model residential areas and are dominantly residential.

B. Monthly Income

Monthly income is an important indicator of economic situation of an area. Monthly income of majority of the people in Sanda is between Rs.5000 to Rs.15000, whereas 44% of the people in Ichra has an income between Rs.10000 to Rs.20000. Majority of the people in slums areas has combined household income of Rs. 6000

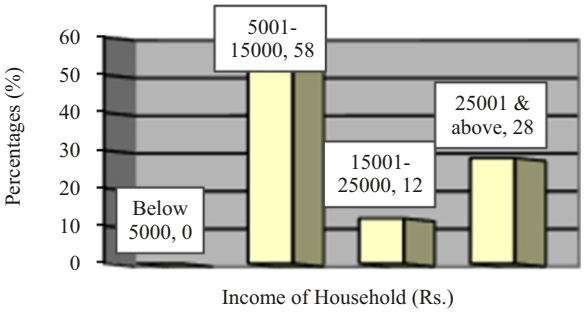

Fig. 1. Income of Households (Sanda)

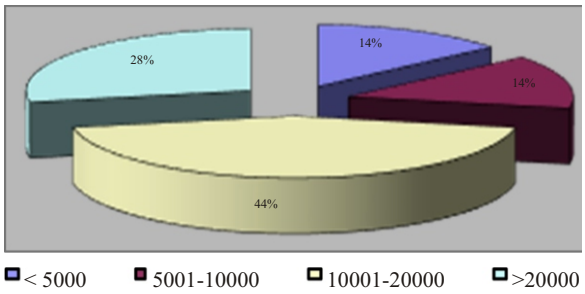

Fig. 2. Income of Households (Ichra)

C. Condition of Buildings

Condition of building is very important to know history, risk associated to the lives of the residents and preservation work. Majority of the building in both areas are in dilapidated condition. Fifty percent of houses in Ichra are in extremely dilapidated (dangerous condition). The building conditions are relatively better in Sanda but 30% are in extremely dilapidated condition. These buildings under Punjab Local Government Ordinance 2001 [xiii] are liable to be demolished partly or completely and may be declared unfit for residence. Punjab Local Government Ordinance Section 34 (3) and section 34 (5) are about such buildings. Section 34(3) states that if a building is in dangerous condition and unfit for human habitation, the concerned local government may prohibit the occupation of this building and ask owner to repair it suitably. Section 34(5) empowers the concerned local government to take action against any block of buildings which is in unhealthy condition. The concerned Local Council may ask owner of building to demolish unhealthy/dangerous part of building at his own and in case of default, the council may take appropriate action and cost incur thereupon shall deem to be recovered from owner or occupier of such building. If building or any part of building is so overcrowded as to endanger lives of tenants or inhabitants, the local council may after inquiry and by notice, not less than one month, ask owner or occupier to decline overcrowding in manner specified in the notice.

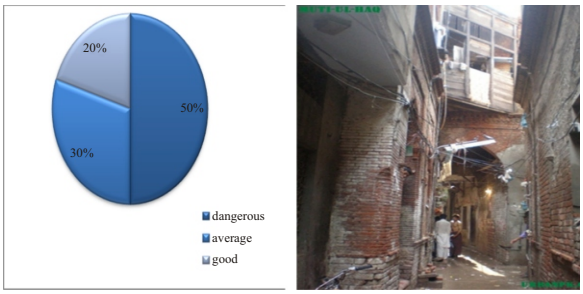

Fig. 3. Condition of buildings in Ichra

D. Number of Stories

Number of stories help to access density of the area. As per prevailing building byelaws the maximum three storeys can be constructed in residential areas. In both areas single storey houses are very short. Most of the houses in Sanda are double storeys. In ichra most of the houses comprises of four storeys. The houses in slums area of Johar town areas are mostly single storeys.

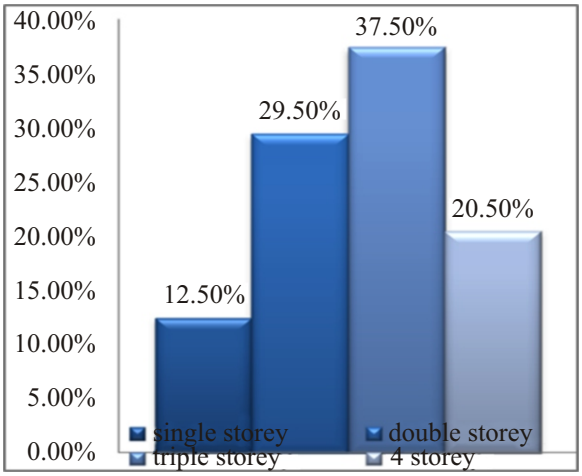

Fig. 4. Number of Storeys of Houses in Ichra

E. Layout of Streets

In both areas the minimum street width is seven feet and maximum is twenty feet. The streets pattern is irregular with few blind curves. The building balcony or terraces are projected beyond the building lines and a few places concurrent projections made the street fully covered. These are constructed in re-erection of the building in complete violation of the existing building byelaws. Furthermore streets are occupied with hanging electricity wires which human hazard and may trigger fatalities. In consulted slums street pattern is irregular but hanging wires are not evident.

Fig. 5. Tapering Streets with Building Projections

F. Drainage and Sewage

No proper sewage system or disposal system is found in these areas. Drains carpeted with sludge and the thrown garbage by people. Due to lack of awareness people drain out their household waste openly. Open man-holes show with waste deposits overflows observed in few streets. Heaps of garbage found at every nook and corner of the especially in Icchra. A highly unhygienic environment is present. However, at few places we see the waste collected by the municipalities. It is a major problem prevailing over the entire area of the Icchra. In rainy days accrued water on roads causes water borne diseases spread all over the area. Slums areas don't face these problems as there is no provision of the drain and garbage is thrown out in open nearby plots of the model areas.

G. Solid waste Management

There is no proper arrangement for the disposal of solid waste in these areas. Heaps of garbage, found everywhere on the roads contributes towards pollution and an unhealthy environment.

Fig. 6. Unattended Waste Materials

The foul smell cause many breathing problems. There is no solid waste collection service in the slums areas.

H. Satisfaction about Utilities and Services

Success and failure of any service tie with satisfactions and trust of the people. In this connection questions regarding key service and public utilities asked from the residents of these localities. Reponses of the residents in terms of their satisfaction for different utilities, services and infrastructure highlighted below. The satisfaction level also helps to draw conclusion for the performance of local/National public institutes responsible for provision of these services.

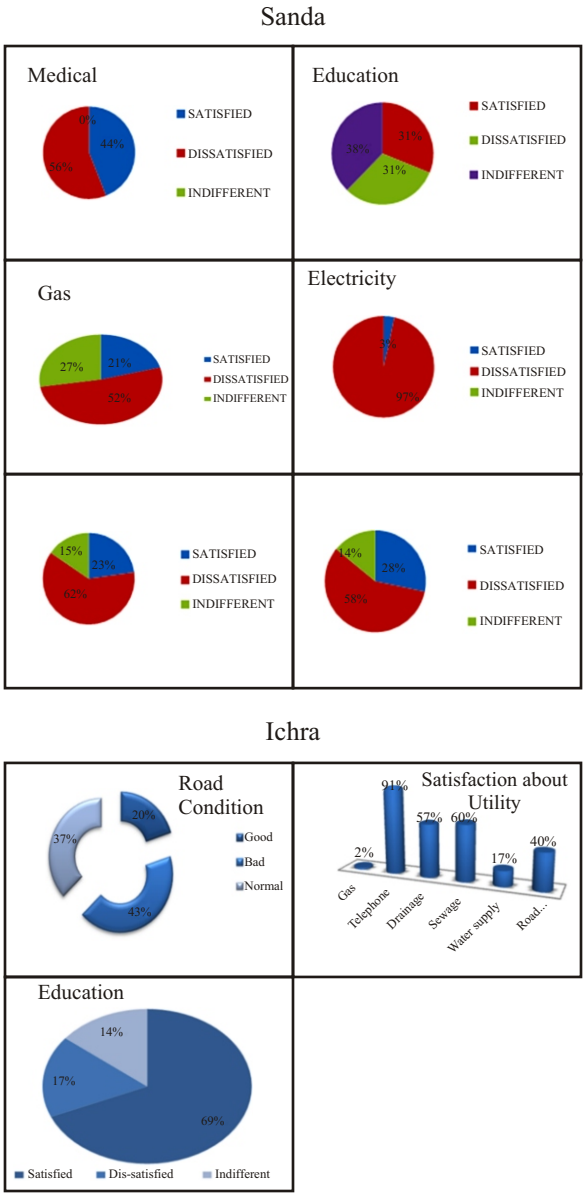

Fig. 7. Percent Satisfaction about Services

IV. Conclusions and Recommendations

There is a symbiotic relationship between economic structure and infrastructure provision. In order to manage urbanization economic growth of city with infrastructure provision especially for the urban poor necessary. The finding of the research with proposed suitable actions summarized below

A symbiotic relationship between economic structure and infrastructure provision has been found in both the selected localities. The founded areas of Lahore practically converted into slums areas with unrelenting pressure of urbanization. City District Govt. may prepare and approve crash programs for revitalization of these areas under section 40(a) which envisages City District Government Lahore to prepare and approve such plans. In fact preparation and approval of these plans included in basic functions of City District Government Lahore.

Houses in both founded areas were in dilapidated condition. In Icchra 50% of the houses were found in dangerous condition. It is foremost important to initiate an action under sections 34(3) and 34(5) of Local Government Act 2013 [xiv] which empowers local governments to declare these houses unfit for habitation or demolish if deem suitable.

A significant proportion of residential buildings 37% was found to rise at fourth storey level, which was a clear violation of building byelaws. Building control is among the key functions of Town Municipal Administration under section 54 and specifically, a function of Town Officer (P&C) under section 53(3). An integrated action specifically in the founded areas requires to be started at the earliest.

Majority of the people in both the localities were not satisfied with services provided by the public agencies. The dissatisfaction of majority of residents about utilities and services point to the fact that in order to manage urbanization economic growth of city with infrastructure provision especially for the urban poor is necessary. A team consisted of local representative people need to set up for coordination and facilitation of the public agencies.

The comparative profiles of these areas with existing slums areas of the city reveals that living standards of these areas are inferior to the consulted slums. Actions for the improvement of living standards need to be taken at priority. In this context Socio-Economic Status Indices (SESI) of different areas may prepare and consult.

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Effect of Cold Work on the Age Hardening Behaviour of Al 2014 Al alloy

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Abstract-The Al 2014 alloy was hardened to a considerable extent by subjecting it to solution-heat treatment at 502C° for 2 hours water quenching and then aging, both natural and artificial. Hardness increased to 113HV from the as-cast value of 85HV during natural aging and increased further to 136HV and 145HV when aged at 180C° and 232C° for only one hour. The hardness increased significantly when the alloy was cold worked to various degrees by rolling after solution treatment and water quenching, and then artificially aged. Maximum hardness values obtained were 188.7HV and 191.6HV which corresponded to 44% and 48% cold deformation respectively at the aging temperature of 180C° for only one hour aging time.

Keywords-Aluminium Alloy, 2014 Aluminium Alloy, Cold Rolling, Age Hardening

I. INTRODUCTION

Aluminum and its alloys have many useful applications due to their excellent combination of properties such as the low density, the good resistance to atmospheric corrosion and high ductility [i]. Due to the use of high strength and age hardening properties, aluminum alloys are common in aerospace industry. These alloys are selected due to their useful combination of physical and mechanical properties which include strength, ductility, fatigue resistance, fracture toughness, and corrosion resistance. In order to obtain the desired set of alloys properties, the correct combination of alloy composition and thermo mechanical processing is essential [ii].

Aluminum 2014 is used for many important structural components of the air craft. This alloy is similar to 2017 and 2024 with respect to a high percentage of copper. It is used where high strength and hardness including service at elevated temperature is required than what can be obtained from 2017 or 2024. [iii]

Aluminum and copper alloys of 2xx series are widely used for their good mechanical strength in the solution treated and artificially aged condition. When loaded near to or above the aging temperature, over-aging process occurs and depletes material properties such as hardness and tensile characteristics [iv].The mechanical properties of Al 2014 and similar alloys could be significantly improved by using precipitation hardening heat treatment [v].

Aluminium alloys have been the major material for the structural components of airplane for more than 80 years because of their well-established design methods, well known performance, manufacturing and reliable inspection techniques [vi]. Aging treatments significantly increase properties of some of Aluminum alloys and their composites, especially of 2xxx and 6xxx series alloys. [vii] Many structural 2xxx aluminum alloys with high Cu and Mg ratios contains Cu in excess of 2 percent by weight and precipitation hardening is the main strengthening method in similar alloys. However, from a durability and corrosion perspective, there are increasing concerns regarding Copper rich Aluminum-alloys,asit is found that higher Cu content associates to relatively low corrosion resistance. There is an emergent concern in Al Mg Cu alloys that posess low amount of Cu and high Mg contents and show improved age hardening responses for emerging automotive applications. [viii]

Reference [ix] studied the influence of cold working and age hardening on Al 6061. It is found that single aging at 180 degree for four hours can improve the strength and mechanical properties but double aging has no effect. [x] compared the effect of cold working on Al 2024, 6061 and 7075 alloys and stain limits are suggested. Forming could be achieved for the tempers that provide low strength and high conductivity. Reference [xi] studied the influence of microstructure on work hardening of Al Mn alloy and one Al Mg Sialuminum alloys and results showed that microstructure had a marked influence on both ductility and work-hardening. Reference [xii] investigated the effect of cold deformation on the age hardening behavior of 2024 Al alloys. It was found the aging behavior is accelerated by large cold deformation and peak strength value could be attained for the aging of 40 minutes.

Reference [xiii] studied the effect of homogenization on cold deformation of 6063, 2014 aluminum alloy by torsion test. This technique has large effect on the microstructure of aluminum alloys and decreases the secondary phase. The extent of cold deformation is improved by homogenization process.

Reference [xiv] determined the effect of large plastic deformation and age hardening on mechanical properties of Al Mg Si alloy. The plastic deformation was provided by equal channel angular pressing (ECAP). It is found the ultimate and yield strength values are improved by two to three times. Aging after ECAP increased the ductility of the material [xiv]. Sever plastic deformations is the application of the methods that generate solid nanomaterials. To achieve large deformations that considerably exceeds the conventional values, special deformation techniques are used. Recently, the best common method used is the technque of equal channel angular extrusion [xv].

Reference [xvi] studied the work hardening and aging effect on 7xxx Al alloy. It is found that many parameters effect the hardening behavior e.g. partical distribution and their size, alloying elements and dislocation density in solid solution.

Reference [xvii] investigated the influence of the strain rate, texture and temper on the performance of an extruded AA7030 aluminium alloy by uniaxial tensile tests. The results reveals that the texture has a strong influence on ductility and plastic flow. However, its effect on ultimate strength, yield strength, and strain-hardening capability is low. Strain rates do not have too much influence on the yield strength and plastic flow. Whereas the strain-hardening and ultimate strength decrease expressively with increasing strain rate and ductility increases. The temper settings strongly influence the strain-hardening capability, ultimate and yield strengths, while their effect on plastic flow is partial. Reference [xviii] discussed that Cold working is suitable for parts with fine geometrical tolerances, smooth surface finish, good concentricity, and for net shape products. However, an increasing need for manufacturing components at a lower cost requires more cost-effective production processes. Forming in warm state is an alternative process that has the advantages of producing complex geometrical profiles in less operation steps as compared to cold forming.

An interaction exists between natural aging and pre-straining which decreases the material properties in the form of flow stress. Therefore, it is necessary to consider the collective effect of aging and plastic deformation in order to predict the mechanical properties with a reasonable accuracy. References [xix-xx] investigated that cold expansion technique is more efficient that produces more even compressive residual stress profile through the hole depth. Therefore, the temperature changes may be not as much of beneficial. It is thought that the higher temperature allows any irregular residual stresses along hole edge and through its depth in order to diffuse a small amount and vary towards the uniform compressive stress profile thus increases resistance to fatigue.

Aim of present work was to improve the mechanical properties, particularly hardness by different age hardening treatments. (T4, T6,and T8). The main objective was to study the effect of rolling on the hardness of the artificially aged alloy in a T8 heat treatment procedure and compare it with the hardness of the alloy in as-cast,artificially aged and naturally aged conditions.

II Material and Experimental Techniques

As-cast 2014 Al alloy used in the present work. Chemical composition is given in the Table 1.

TABLE I
Chemical Composition of 2014 Aluminium Alloy (Wt%)

	Cu	Mg	Mn	Fe	Si	Zn	Al
Wt %	4.5	1.40	0.62	0.18	0.10	0.1	Balance

The as-cast alloy was in the form of 20mm diameter and 6 inch long bars. A slice of 200mm x 200mm was cut from the bar material and its initial hardness was measured. All the bars were homogenized by solution treatment in a Muffle type furnace at 502C^{o} for 2 hours and then quenched in water for 4 to 5 minutes at room temperature. One bar was cut into three pieces of 200mm x 200mm size. The hardness of one sample was measured after homogenization and remaining two were artificially aged at 180C^{o} and 232C^{o} for 1 hour and then allowed to cool down at room temperature and then their hardness was measured. The remaining five bars were subjected to cold rolling in a STANAT rolling mill. The bars were deformed to different percentages. Three set of samples of 200mm x 200mm were cut from each deformed to a given percentage. Hardness of one set was measured before aging mechanism. Remaining two sets were artificially aged at 180C^{o} and 232C^{o} for 1 hour and then allowed to cool down to room temperature. Finally the hardness of these deformed samples was measured. The hardness values of heat treated samples were determined by using Vicker's hardness testing machine.

III Results and Discussion

The hardness testing results of as-cast and solution treated, quenched and naturally aged samples (T4 process) are given in Table II, and hardness values of solution treated, quenched and artificially aged samples (T6 process) are given in Table III. Solution treatment temperature (502C^{o}) and time (2 hours) were the same for the two processes. It may be seen from These results that the hardness of the naturally aged sample increased to 113HV from the as-cast value of 85HV. The hardness of the sample increased further to

136HV and 145HV when artificially aged for one hour at 180C° and 232C° respectively.

TABLE II
VICKER'S HARDNESS OF SOLUTION TREATED SAMPLES

Solution treatment		Vicker's Hardness
Temperature (C°)	Time (h)	(HV)
As-Cast	--------	85
502C°	2 hour	113

TABLE III
VICKER'S HARDNESS OF SOLUTION TREATED AND AGED SAMPLES

Solution Treatment		Aging	Vicker's Hardness	
Temperature	Time	(HV)	Time	Temperature
136	1h	180C°	2h	502C°
145	1h	232C°	2h	502C°

TABLE IV
VICKER'S HARDNESS OF SOLUTION TREATED, COLD ROLLED AND ARTIFICIALLY AGED SAMPLES

Solution Treatment		% rolling	Vicker's Hardness		
Temp. (C°)	Time (h)	After solution treatment & quenching	Before aging (HV)	After aging at 180C° for 1 h (HV)	After aging at 232C° for 1 h (HV)
502	2	18	152.1	156.2	157.8
502	2	22	154.6	169.0	169.0
502	2	26	157.4	176.5	176.8
502	2	44	164.7	188.7	179.0
502	2	48	176.2	191.6	185.6

The hardness testing results of the samples which were subjected to T8 treatment i.e, solution treatment, quenching, cold rolling and artificial aging are included in Table IV. The solution treated and quenched samples were immediately cold rolled to different percentage. These were 18%, 22%, 26%, 44% and 48%. It may be seen from the data that after rolling, the hardness of the samples have significantly increased as compared to as-cast, naturally aged and artificially aged samples reaching a maximum value of 176.2HV (corresponding to maximum deformation of 48%). The results also show a continuous increase in hardness of the samples with the increase in the amount of deformation, as expressed graphically in Fig. 1. It may also be seen that even the smallest amount of plastic deformation increases a hardness of 152HV in the as-cast, solution treated and subsequently quenched specimen.

All the cold rolled specimens were aged for one hour at 180C° and 232C°. The hardness testing results, are given in Table IV and are expressed graphically in Figures 2 and 3. These results show a further increase in hardness of the cold rolled samples. The observed increase in hardness was found to be more at the aging temperature of 180C° then 232C° respectively. Therefore, the maximum hardness value obtained for the 2014 Al alloy correspond to those samples which were solution treated at 502C° for 2 hours, water quenched, cold rolled to 44% and 48% reduction in dimensions and then aged at 180C° for one hour. The maximum hardness values obtained were 188.7HV and 191.6HV corresponding to 44% and 48% reduction in dimensions respectively by cold rolling.

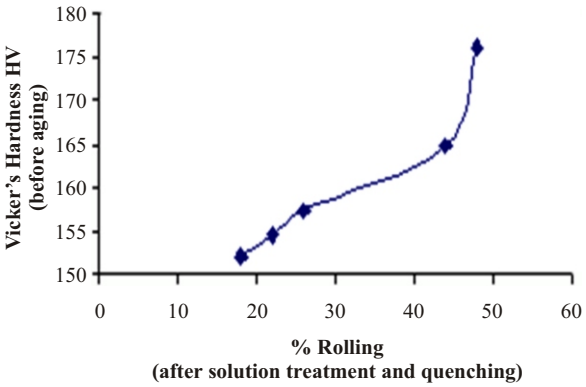

Fig. 1. %Rolling Vs Vicker's hardness

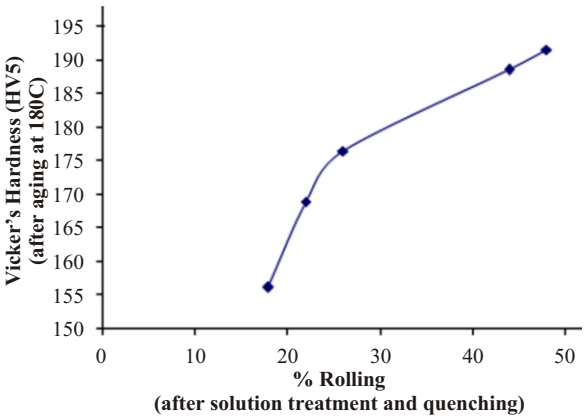

Fig. 2. % Rolling Vs Vicker's hardness.

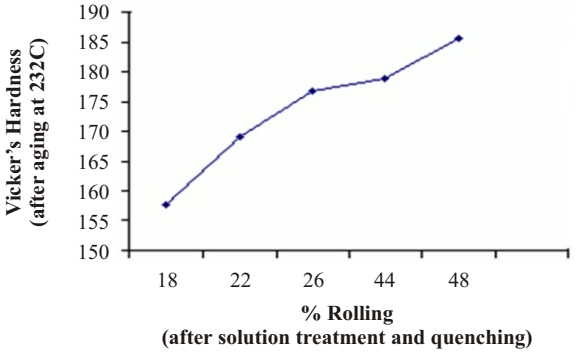

Fig. 3. % Rolling Vs Vicker's hardness

In a previous work on the same alloy [ii] reported an increase in hardness of the alloy by using T6 heat treatment conditions. The Al 2014 alloy was shown to exhibit a maximum increase in hardness from a as-cast value of 71.5HV to 148.8HV during an aging treatment carried out at 190C° for 7 hours. In present work, the maximum hardness values obtained were 137HV and 145HV at aging temperatures of 180C° and 232C° respectively in a similar aging treatment but the aging time selected was only one hour at both the temperatures as compared to 7 hours. Also, increase in hardness of the as-cast material 85HV to 137HV and 145HV was reasonably high while using a very short aging time of one hour. These values then increased even further using T8 heat treatment using the same short aging time of one hour, as described above.

CONCLUSIONS

Following conclusions may be drawn from above work on Al 2014 alloy

1. The hardness of the as-cast alloy increased from 85HV to 113HV when it was solution treated at 502C°, quenched and naturally aged (T4 treatment).
2. The hardness of the as-cast alloy increased from 85HV to 136HV and 145HV when solution treated at 502C°, quenched and artificially aged for one hour at 180C° and 232C° respectively (T6 treatment).
3. The hardness of the as-cast alloy was significantly increased when the alloy was subjected to various degrees of cold work after solution treatment at 502C° followed by water quenching. The maximum hardness obtained was 176HV corresponding to the maximum deformation of 48%.
4. Artificial aging of the solution treated, quenched and cold rolled alloy showed a higher increase in the hardness at 180C° than 232C°.
5. Maximum hardness values of solution treated, quenched and cold rolled alloy were found to be 188.7HV and 191.6HV corresponding to 44% and 48% cold deformation respectively and an aging temperature of 180C° for one hour's aging time.
6. Maximum hardness obtained in the alloy after solution treatment, cold working and aging at 232C° for one hour was found to be 185.6HV.
7. Increase in the hardness of the alloy during aging at both temperatures (180C° and 232C°) corresponding to increase in degree of cold work after solution treatment and quenching.

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Optimization Strategies for Improving Irrigation Water Management of Lower Jhelum Canal

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Abstract-The paper includes computing crop water requirement, identification of problems and optimization strategies for improved irrigation water management of a canal command. Lower Jhelum Canal (LJC) System was selected as a case study. Possible strategies for optimization are enhancing irrigation water productivity by high value and high yield crops, adoption of resource conservation interventions (RCIs) at the farm level, improving irrigation system efficiency and its management. Estimation of daily reference evapotranspiration of LJC command was carried out by Penman Montieth - 2000 method and metrological data of Sargodha for the period 1999 to 2010 was used. Crop water requirements were computed from reference evapotranspiration, crop coefficients and periods of crops for existing cropping pattern. The comparison of the crop water requirements and available water supplies indicated shortage of more than 51% in Kharif and 54% in Rabi seasons. The gap between requirements and supplies is fulfilled by groundwater in the command. The structural measures identified in the present study for improving canal management include rationalization of canal capacities in keeping with the current water requirements and availability, rehabilitation and remodeling of canal network and lining of distributaries and minors in saline groundwater areas. An array of measures and practices identified for improved water management at the farm level include: improvement and lining of watercourses, proper farm design and layout, adoption of resource conservation technologies involving laser land leveling, zero tillage, and bed-furrow irrigation method. Adopting proper cropping systems considering land suitability and capacity building of farming community in improved soil, crop and water management technologies would enhance the water productivity in an effective and sustainable manner.

Keywords-Irrigation Management, Optimization Strategies, Reference Evapotranspiration, Canal Water Management, Lower Jhelum Canal

I. INTRODUCTION

Irrigation is essential in Pakistan due to its larger share of 24.1% in country's gross domestic product (GDP) [i]. The significance of managing irrigation water, its practices, standards and scope differ to large extent depending on its economic growth and water scarcity in a country. Effective irrigation management ensured sustainability in farming and productivity. Irrigation management provides extent of sustainable farming and reduces poverty, hunger and starvation [ii]. Presently, irrigated agriculture enterprise in semi-arid and arid regions of the world is confronted with major challenge of addressing the interactive triangle of food security, environmental sustainability and poverty alleviation by improving the livelihood of the farming community. Also, competition among different water uses and users is increasing with time, especially under the water scarcity situation. This reflects water management by bringing more area under agriculture, increasing cropping intensity along with increased land and water productivity, sustaining land and water quality and improving farm economic returns. Wheat is the most extensively grown / consumed cereal food for 35 % of world's population. Moreover, it contributes over 45% of wheat production in the developing world [iii, iv]. Resource conservation interventions (RCIs) including laser land levelling (LLL), zero tillage (ZT) and bed and furrow (BF) have prime role to achieve sustainable agriculture output, reducing crop inputs and enhancing the resources' efficiency. It was concluded that these interventions enhanced the agriculture yield and water saving. Irrigation water saved by RCIs was upto 771 m^3/acre in the selected irrigated areas of Punjab, Pakistan [v].

II. LOWER JHELUM CANAL (LJC): A CASE STUDY

Lower Jhelum Canal (LJC) off takes from river Jhelum at Rasul head-works and irrigates areas of Chajj Doab in Districts Sargodha, Mandi Baha-ud-din and

Jhang in Punjab, Pakistan. The gross command area (GCA) of LJC is 0.657 million hectares (1.635 million acres), culturable command area is 0.610 million hectares (1.518 million acres) and cropping intensity is 121% [vi]. The command area of LJC is shown in Fig. 1. LJC was opened in 1901 with original design discharge capacity of 102.03 cumecs (3600 cusecs). Its capacity was increased to 156 cumecs (5500 cusecs) in 2002 due to increasing demand. Provincial Irrigation department has proposed further increased discharge carrying capacity to 187.0 cumecs (6600 cusecs) for which remodeling of the canal is being done. The length of canal is about 60 Km. Fig. 1 shows location of LJC command.

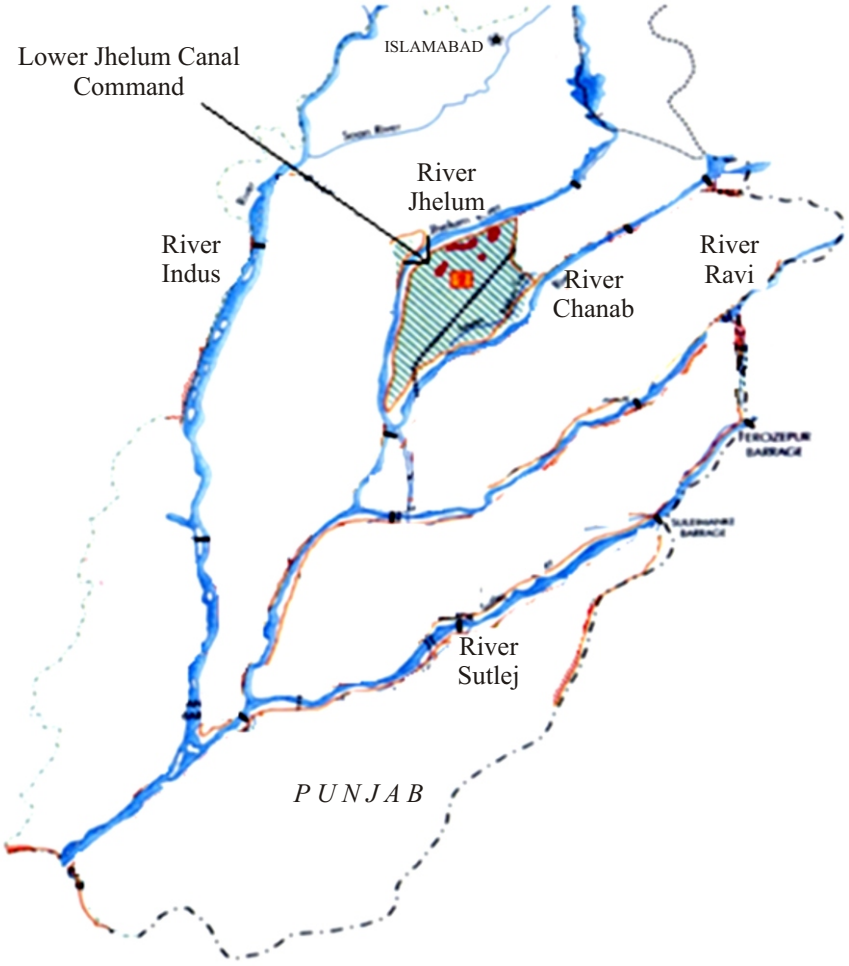


Fig. 1. Location of LJC command Area

III. DATA USED

The following data has been used in the study:

3.1 Climatic Data

Sargodha is the only meteorological station estimating climatic parameters in the LJC command. Daily values for maximum and minimum temperature, wind speed, humidity, daily sunshine hours from 1999 to 2010 were collected for the case study from Regional Meteorological Centre (RMC) Lahore (RMC, 2010, unpublished data). Average monthly values of humidity, wind speed, maximum and minimum temperatures, sunshine hours and rainfall for Sargodha Meteorological Station, Pakistan are shown in Table I.

TABLE I
HUMIDITY, WIND SPEED, MAXIMUM AND MINIMUM TEMPERATURES, SUNSHINE HOURS AND RAINFALL AT SARGODHA METEOROLOGICAL STATION, PAKISTAN

Sr. No.	Month	Mean Monthly Relative Humidity (%)	Mean Monthly wind speed (m/s)	Mean Monthly Max. Temperature (°C)	Mean Monthly Min. Temperature (°C)	Total Monthly Sunshine Hours (h)	Total Monthly Rainfall (mm)
1	January	73.8	0.87	18.29	5.1	162.2	25.2
2	February	62.6	1.35	22.95	8.4	197.2	27.4
3	March	56.6	1.81	28.18	13.6	249.0	21.0
4	April	41.2	2.11	35.39	19.8	262.7	23.3
5	May	36.5	2.41	40.24	24.8	270.6	38.6
6	June	43.4	2.88	40.86	27.3	264.4	37.2
7	July	60.7	2.84	38.08	27.9	228.0	129.0
8	August	65.2	2.27	37.26	27.4	243.5	108.7
9	September	61.6	1.74	36.09	25.0	260.3	40.6
10	October	60.3	1.03	32.94	19.0	254.8	12.3
11	November	64.6	0.54	27.25	11.8	198.4	9.2
12	December	70.5	0.55	21.84	6.4	197.4	16.4

3.2 Cropping Pattern / Intensities for LJC System

Cropping pattern is obtained by averaging crop reporting data available with Punjab Agriculture Department and Punjab Irrigation Department for the period 1998 to 2010 (unpublished data). Analysis of cropping data indicates the intensity of 59% and 62% for Kharif and Rabi seasons respectively with average annual cropping intensity of 121% for LJC command area. The cropping pattern and intensities of LJC system are shown in Fig. 2a and 2b.

3.3 Crop Coefficients, Kc

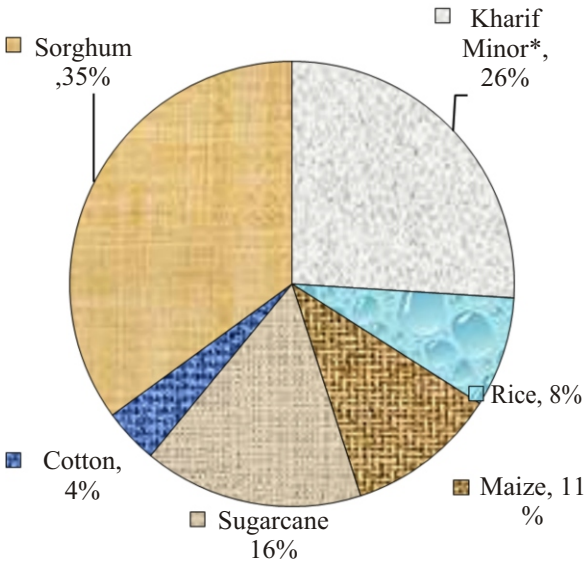
A study was conducted by [vii] to find out the crop coefficients Kc of different crops based on state of the art procedure described in FAO Irrigation and Drainage paper No. 56 (Food and Agriculture Organization (FAO)) [viii]. Same values for crop coefficients Kc of the crops cultivated in LJC command have been used in the analysis. Kc curves of two major crops i.e. wheat and sorghum in the study are shown in Fig. 3a and 3b.

3.4 Lower Jhelum Canal Discharge

Actual average 10 daily discharges of LJC for 19992010 have been collected from (Punjab Irrigation and Power Department (PID), 19992010, unpublished data). The allocated discharges are those given in the Water Apportionment Accord 1991 document. The comparison indicates that available supplies are 10% lesser than the allocated water supplies. The allocated and supplied average 10 daily discharges of LJC are shown in Fig. 6.

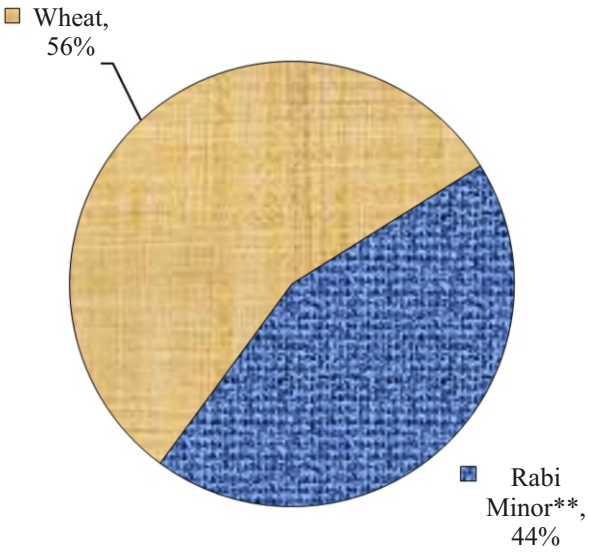
3.5 Irrigation Efficiency

Irrigation looses from head of canal to the root zone of crops in the fields are high and must be included in analysis. Several studies have been carried out in the Indus Basin to estimate conveyance losses upto field level. The findings of some studies have been summarized in Table II. ACE [ix] discussed that the existing efficiency of canal, distributaries/minors, water courses and field is 88%, 83%, 75% and 70% respectively. The overall efficiency reported by ACE [ix] was 38.25%. Directorate of Land Reclamation (DRL) [x] estimated 16.8% losses in main canals, 20% in watercourses, and 25% field losses which leaded to an overall efficiency of about 40%. To compare the crop water requirements and the availability of the canal command it is essential to find out the efficiency of the system. In this study the efficiency of 38.25%, as used by DLR has been used for LJC command.



* Kharif Minor Crops includes mainly jawar, chari, garden, rouni and oil seeds.

Fig. 2a Pattern and intensity for Kharif Crops



** Rabi Minor Crops includes mainly barley, mixed grains, grams, fodders, garden and rouni

Fig. 2b: Pattern and intensity for Rabi Crops

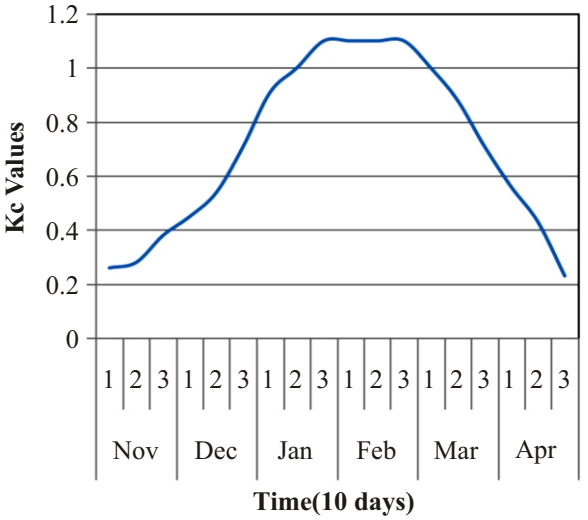


Fig. 3a Kc curve for wheat crop

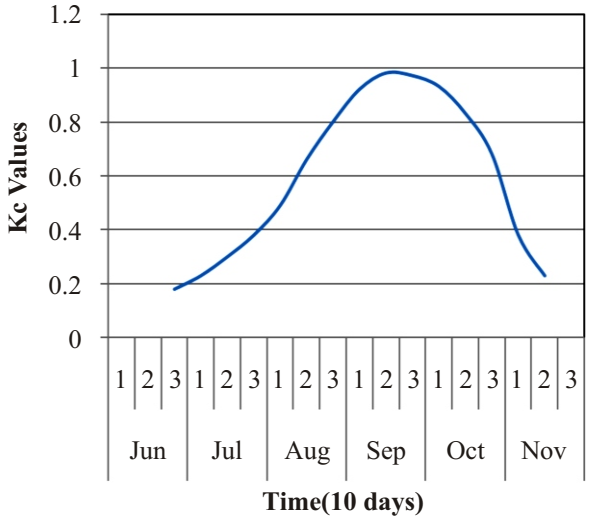


Fig. 3b Kc curve for sorghum crop

IV. Estimating Crop Water Requirements

Evapotranspiration (ET) is required for estimating volume of irrigation water necessary for satisfying seasonal as well as short term irrigation water needs of farms, fields and projects. It is one of the important parameter for designing, planning and operating irrigation/water resources system. The wrong computation of the requirements leads to failure of performance and wastage of water resources. For planning and design purposes, irrigation water requirement has to be studied with respect to the magnitude and variability of the seasonal and peak period irrigation water requirements [xiii].

TABLE II
Efficiencies and Losses of Canal Systems by Different Studies

Sr. No.	Source	Losses (%)	Efficiency (%)
1	ACE[ix]	61.75	38.25
2	DLR [x]	61.75	38.25
3	Ministry of water and Power [xi]	60	40
4	Federal flood commission (FFC) [xii]	60	40

4.1 Estimation of Reference Evapotranspiration (Eto)

Different methods are available in literature to estimate Reference Crop Evapotranspiration (ETo). These methods were reviewed to find out the method that gives best estimated results for Reference Crop Evapotranspiration (ETo). As discussed by Walter [xiv] in ASCE task committee report, "Based on an intensive review of reference evapotranspiration calculated for 49 sites throughout the United States, ASCE Standardized Penman Montieth - 2000 found to be reliable and recommended its use for calculating reference evapotranspiration (ETo), crop evapotranspiration (ETc) and developing new crop coefficients (Kc)". So the same method has been used in the present study. The daily (ETo) of LJC command was estimated using metrological data for the years 1999 to 2010 of Sargodha (the only station falling in this canal command) obtained from Regional Meteorological Centre (RMC) Lahore (unpublished data). Estimated 10-daily average ETo for the station using the Penman Montieth - 2000 is given in Figure 4 and annual ETo works out to be 1646 mm.

4.2 Crop Evapotranspiration (Etc) for LJC System

Estimation of crop evapotranspiration (Etc) of crops cultivated in LJC command area were obtained by multiplying ETo by the crop coefficients, Kc (Etc = Kc x ETo). The values of crop evapotranspiration (Etc) are given in Fig. 4 for the crops cultivated in LJC command. The requirements on 10-daily basis were estimated using Crop Evapotranspiration and reported cropped area. The water requirements at the canal head for the Rabi and Kharif crops are estimated considering 38.25% system efficiency, which has been taken from draft report of National Water Policy [ix] and are shown in Fig. 5.

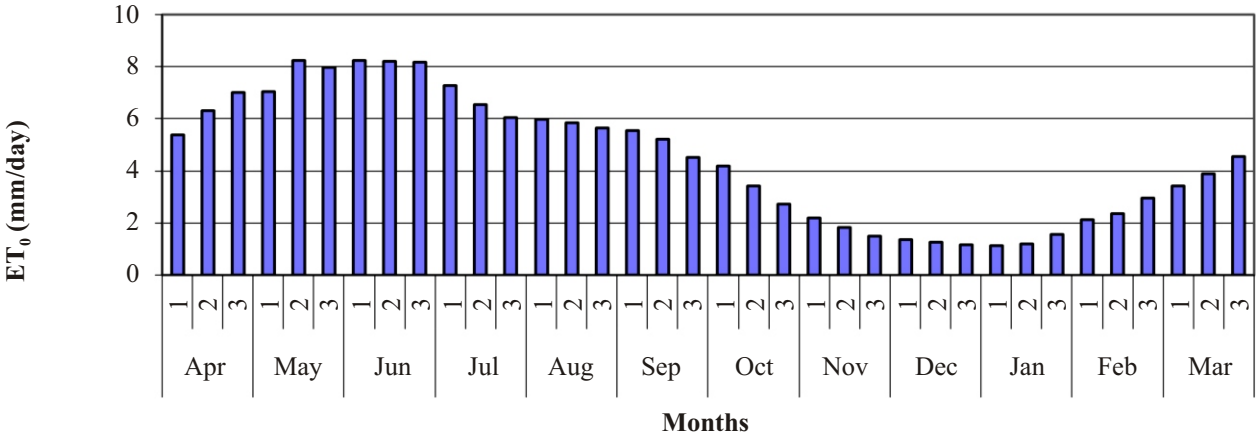


Fig. 4. Average Reference Evapotranspiration (Eto)

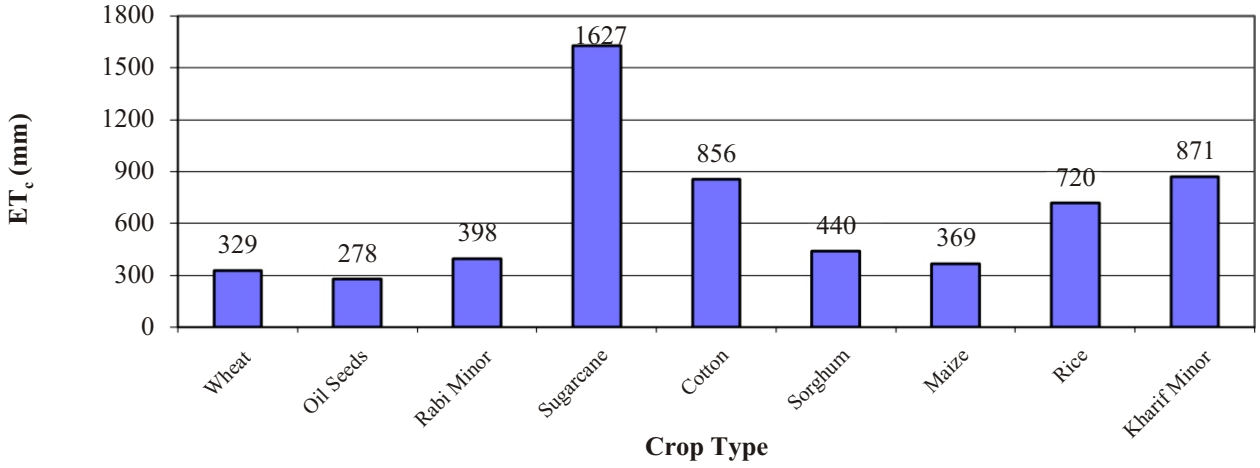


Fig. 5. Etc values for different crops cultivated in LJC command areas

4.3 Comparison of Crop Water Requirements and Availability

The crop water requirements are compared with available canal water supplies at canal head for Rabi and Kharif seasons and are shown in Fig. 6. The comparison of irrigation crop-based requirements has been estimated at 38.25% efficiency. The analysis has also been carried out excluding and including rainfall to find out how 10-daily crop water requirements vary with rainfall. The analysis shows that the shortage of crop water requirements and available water supplies is reducing, as the efficiency of the system increases. The results reveal total crop based irrigation requirements of about 2.7 BCM and shortfall of about 45% for the scenario of 38.25 % system efficiency including rainfall. The shotfall further increases to about 59 % by excluding rainfall in the analysis. Fig. 6 depicts larger deficit during the months of July, August and September in Kharif season and February and March in Rabi season.

It also shows that available surface water supplies cannot meet the crop water requirements and groundwater is abstracted to abridge the gap between demand and supply. The groundwater of LJC command is of marginal quality. The excessive use of groundwater for irrigation reduces the crop yields and increases salinity. The conjunctive use of canal and groundwater in optimized proportion has been suggested to get maximum crop yields and reduces the trend of increasing salinity.

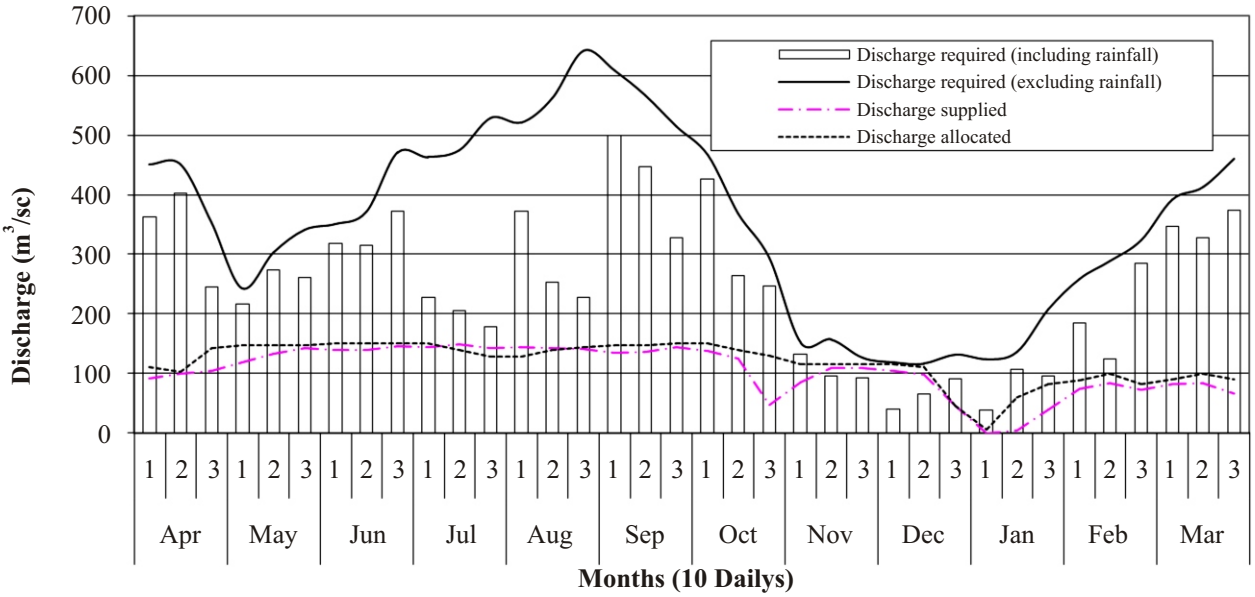


Fig. 6. Comparison of water required, supplied and allocated on 10 Daily Basis at Canal Head

V. Issues of Lower Jhelum Canal Command

LJC has served its useful life of 100 years, with minor repair and maintenance. With the population growth, stress irrigation and adoption of modern farming and techniques, vast tracts of barren land was brought under cultivation for which the capacity of LJC was increased. Upto 2008, LJC was badly deteriorated. The banks of the channel were in a worn out state and inadequate freeboard was available in many reaches. All the hydraulic structures, being more than 100 years old, had been deteriorated and were generating undulating flow on downstream side in the channels. The channel prism had widened and a lot of cattle ghat sites have rendered the prism in a wild shape. Gates and gearing machinery being as old as the LJC system itself had eroded badly. Most of the channels were running in a precarious condition and these are unable to convey the required discharge. Breaches occurred very frequently, which interrupted supplies to farmers. Also inefficient water application methods (wild flooding techniques), improper land leveling, poor condition and layout of water courses were observed. As such, the water conveyance and water application losses had been increased and the system was losing efficiency day by day. In the circumstances as explained above, a project for Rehabilitation of Lower Jhelum Canal was executed from 2005 to 2008 to rectify all the problems as discussed above. The remedial measures implemented include but not limited to the following: i) earthwork to achieve the desired channel section, ii) earthen banks strengthening by stone pitching along with apron, iii) rehabilitation of hydraulic structures along with stone pitching and apron at their upstream and downstream iv) provision of pushta to cater for hydraulic grade line. Moreover, concrete lining of distributaries and minors were also started in 2008 and it is in progress.

VI. Possible Scenarios for Optimization of Irrigation Water Management

The possible strategies of optimization are enhancing productivity of water by high value and high yield crops, increase efficiency, applying RCIs, improving irrigation system and on-farm water management. Reference [xv] discussed that developed countries are shifting the trend from water productivity and crop yield to high value crops. The profitability of high value crops is much higher than the low value crops. Other economic indicators like IRR of high value crops are also higher than other crops. The high value crops like fruits, vegetables can also sustain in drought season.

High value/yield crops can provide huge economic return. For example olive plantations and modern vineyards needs less than 2,500 m^3/ha of water and their water productivity is equivalent to cotton or sugar having three times more evapotranspiration [xvi]. Fig. 7 shows road map for improving the irrigation water management at canal command level.

VII. Improving Irrigation System and On-farm Water Management Strategies

The structural measures identified in the present study for improving canal management and conveyance efficiency of the LJC system, include rationalization of canal capacities in keeping with the current water requirements and availability, rehabilitation and remodeling of canal network and lining of distributaries and minors in saline groundwater areas. For rehabilitation and remodeling of canal involves improving the channel prism to cater for enhanced discharge, raising and strengthening of canal banks, providing cattle ghats, upgrading hydraulic structures had been suggested. Suggested water management measures are regular water flow measurements to ensure adequate, reliable and equitable water distribution at different levels of LJC irrigation system and participation of farmers in the operation and maintenance of canal system using the ongoing reforms framework, whereby the farmers are being empowered for management of the distribution network.

An array of measures and practices identified for improved water management at the farm level include: improvement and lining of watercourses, proper farm design and layout, adoption of resource conservation technologies involving laser land leveling, zero tillage, and bed-furrow irrigation method. Adopting proper cropping systems considering land suitability and capacity building of farming community in improved soil, crop and water management technologies would enhance the water productivity in an effective and sustainable manner.

Resource conservation interventions (laser land leveling, bed & furrows and zero tillage) can save 50% water and increase the crop yield upto 25% [xvii]. Reference [xviii] concluded that laser land leveling (LLL) can enhance crop yield from 20 to 35% and save 25% irrigation water. The use of RCIs can save 20 to 30% irrigation water [xix] . Reference [xx] evaluated the impact of resource conservation techniques on water and land productivity. These techniques were tested on 200 acres of land (Mona Reclamation Area) in LJC command. It was concluded that average yield/acre for wheat crop in case of laser leveling was the highest with 1856 kg/acre followed by zero tillage with 1812 kg, bed & furrow with 1673 kg and conventional farms with 1615 kg/acre. On an average 0.30 AF of water per acre could be saved by adopting zero tillage technology besides saving a pre-sowing irrigation. Moreover, significant quantity of water could be saved by adopting laser land leveling & bed and furrow method of wheat sowing.

Reference [i, xxi] recommends increase in irrigation system efficiencies to 45%. While there may be uncertainty as to whether this can be achieved, there is significant scope for this modest increase, through farmer education in water application in the field and through on-farm water management in the form of lining watercourses. The use of RCIs has proved several benefits to wheat farmers. Water can also be saved upto 34% by using ridge furrow of 660cm wide [xxii, xxiii].

The demand side management by optimized cropping pattern can improve crop productions and reduce the pressure of water shortage to some extent. The growth of high delta crops should be avoided. The crops grown in LJC command need to be rationalized so that the pattern of crops provides high water productivity and crop yield. The traditional pattern of wheat-rice has resulted better economic return. The sugarcane crop has resulted poor water productivity and allocation of resources. Awareness should be created among the farmers to discourage the growth of sugarcane. The water productivity of Orchards is very high and also these are high value crops. The area is also very famous for oranges, which is liked all over the world. Key crops identified in the study for LJC command are wheat and orchards for Rabi season and rice, cotton and orchards for Kharif season. The cropping intensity of these crops may be increased so as to make the cropping pattern optimized. Reference [xxiv, xxv] suggested that several organizations are involved in management and distribution of water, on farm water management and revenue collection at canal command levels in Pakistan. Generally there seems to be lack of coordination and overlap of activities among the agencies causing poor overall performance. It may be advisable to provide a single

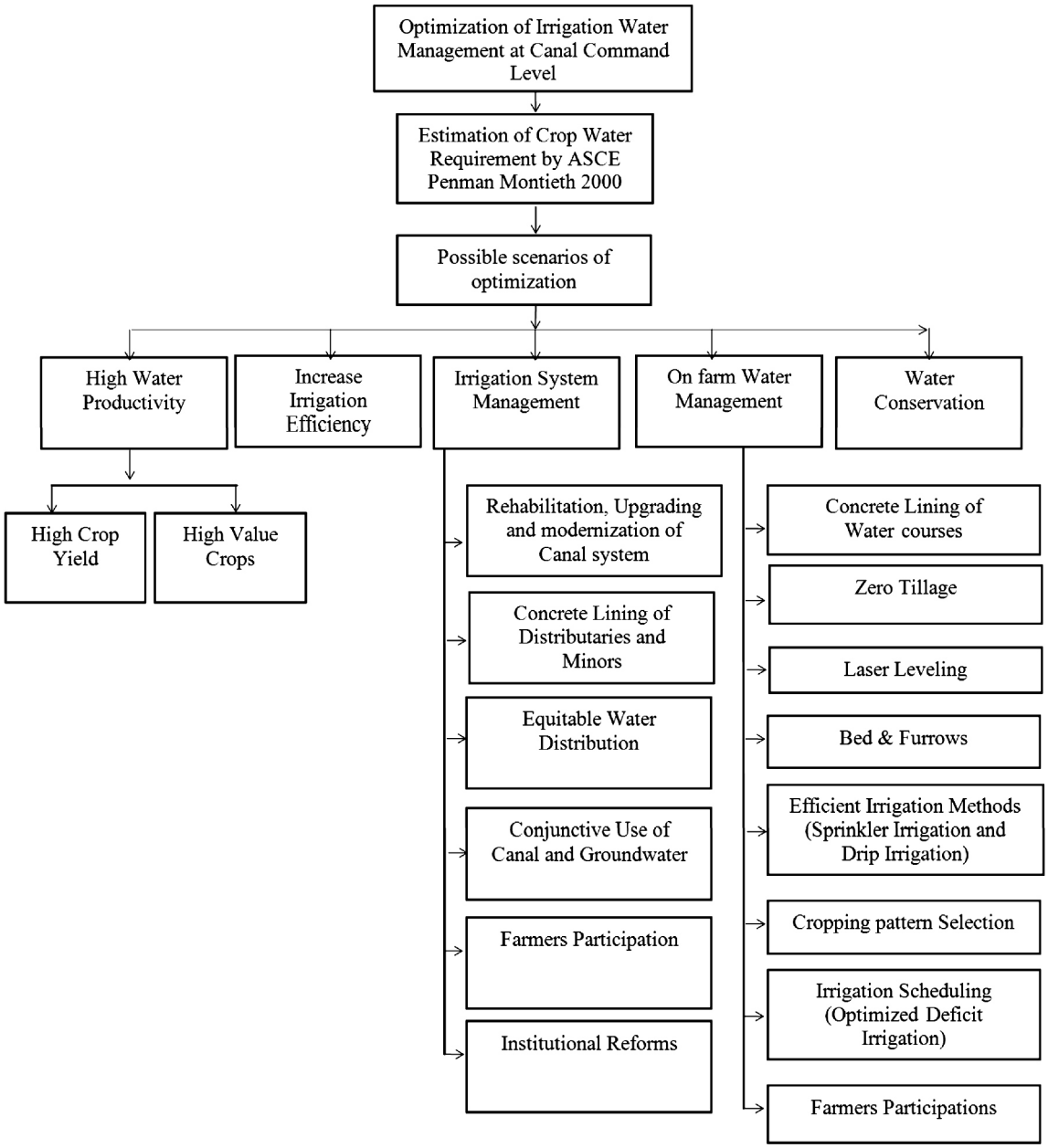


Fig. 7. Schematic Diagram of Optimization of irrigation water management at Canal Command Level

administrative unit bringing together all stakeholders. The last but not the least, the participation of farmers in management needs to be enhanced in real terms to create within them a sense of owner ship of the system. The results of the present study of 45% shortfall at 38.25% efficiency are compatible with the findings similar study conducted by [xxv] for canal water management of Upper Chanab Canal (UCC) in Pakistan. The crop based irrigation water requirements of UCC computed was 2 BCM leading to shortfall of more than 40% on an annual basis at 40% overall system efficiency. The prospective measures identified in the study for reducing shortfall included enhancement in canal supplies, change in cropping pattern, canal lining and on farm water management.

The constraints for implementing the optimization strategies identified in the study include: physical constraints due to poor operation and maintenance of the system and inadequate water control structures. Institutional constraints due to public sector monopoly, lack of coordination among different institutions and agencies, limited specialization and skilled staff, limited involvement of farmers in irrigation management. Financial and economical constraints due to inadequate cost recovery and provisions for operation and maintenance of irrigation system.

VIII. CONCLUSIONS

The following conclusions may be drawn from the present study:

1. The comparison of actual crop water requirements and available water supplies indicates a shortage of more than 50% for LJC system on annual basis.
2. The shortfall in availability and requirements is met by pumping groundwater of marginal quality. A comprehensive study is needed for optimized conjunctive use of surface and groundwater to minimize the ill effects of increasing salinity.
3. The possible strategies of optimization are enhancing the water productivity by high value/yield crops, improving irrigation system and on-farm water management/efficiencies and adoption of resources conservation interventions. An array of measures and practices identified for improved water management at the farm level include: improvement and lining of watercourses, proper farm design and layout, adoption of resource conservation technologies involving laser land leveling (LLL), zero tillage (ZT), bed-furrow (BF) irrigation method.
4. The structural measures for improving canal management include rationalization of canal capacities, rehabilitation and remodeling of canal network and lining of distributaries and minors in saline groundwater areas. Suggested water management measures are regular water flow measurements to ensure adequate, reliable and equitable water distribution at different levels of LJC irrigation system and participation of farmers in the operation and maintenance of canal system

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Reduction of Computational Time for a Robust Kalman Filter Through Leroux Gueguen Algorithm

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Abstract-Data loss is a frequent dilemma in many processes including state estimation. These lost data samples are normally reconstructed by employing linear prediction theory. Three various linear prediction schemes that includes Normal Equation (NE), Levinson-Durbin Algorithm (LDA) and Leroux Gueguen Algorithm (LGA) may be employed to reconstruct the data loss. The NE method suffers from high computational complexity. On the other hand, LDA is computationally less expensive but it has large dynamic range problem in Linear Prediction Coefficients (LPCs). The LGA overcomes the drawbacks associated with NE and LDA schemes. The major contribution of this paper is the reduction of computational time raised by NE method by employing a modified LGA technique. The upper limit of linear prediction filter order is decided by a minimum mean square error based algorithm. The simulation results are shown by employing this modified LGA on a standard Mass-Spring-Damper system.

Keywords-Linear Prediction Schemes, Kalman filter, Leroux Gueguen Algorithm, Linear Prediction Coefficients, Normal Equation

I. INTRODUCTION

Linear prediction is in fact a system identification process where a signal is reconstructed from its previous signal samples [i]. In other words, linear prediction is a mathematical and intensification tool for estimating the future values of a signal based on its previous values (and sometimes input as well). The theory of linear prediction has been extensively used in a variety of engineering applications [ii]. Its diverse range of applications can be found in speech coding, speed recognition, model based spectral analysis, signal restoration, video coding, model based interpolation and impulse/step input detection [iii-iv].

In linear prediction a signal window comprised of previous samples is selected to reconstruct the lost data. In order to minimize the mean square error, the weights are assigned according to their contribution to this data [v]. These weights are called linear prediction coefficients. Three linear prediction coefficient techniques namely Normal Equation, Levinson Durbin Algorithm and Leroux Gueguen Algorithm may be employed to reconstruct the lost data. During the last decade, overcoming the side issues emerged from missing data in control and communication systems are prevailed as open research problems for researchers [vi].

Perhaps, the best available tool for the linear estimation problem is Kalman filtering. Kalman filter performs estimation based on noisy measurement data and input. Normally in Kalman filter there are two steps; (a) predicts the states of a system, (b) then update the states using measured data. In case of loss of measured data the update step will not be performed and the estimation of conventional Kalman filter may not be accurate. To remove this drawback, an alternative method Open-loop Estimation is used to estimate the state of a system [vii]. In Open-loop Kalman filter scheme only prediction is performed in the absence of data. And when the data reoccurs then update is performed. However this scheme produces unbounded estimation error, when the data loss occurs for an adequate time period [viii-ix]. To estimate the state of a system more accurately, an optimal estimation techniques is required, which can reduce the estimation error to its bound in case of data loss [vi].

As mentioned above, there are three LPCs techniques that are used to reconstruct the missing measurements. The NE method has been found computationally expensive due to involving larger matrix inversion in calculating LPCs [v]. The LDA avoids the matrix inversions involved in conventional Normal Equation method and hence it reduces the computational cost. However, LDA suffers from large dynamic variety in the values of LPCs [x]. Theoretically speaking, it is observed that no limit can be made on the value of LPCs computed through LDA [xi].

On the other hand, LGA removes the issues associated with LDA in a fixed-field by using the application of Schwartz inequality in computing LPCs through this scheme [x]. The LGA method also avoids the inversion of large matrices involved in NE, hence reduces computational time. This paper emphasis on the implementation of LGA for a Mass-Spring-Damper

system in order to (a) test the performance of LGA and(b) provide another platform of handling data. The LerouxGueguen Algorithm is a better solution in a non-variable environment since the scale of intermediate variables is bounded [xii]. The core objective of this paper is to reduce the computational time in calculating LPCs through LGA as compared to NE method.

The rest of paper is organized as follows: In Section II, an overview of discrete-time Kalman filtering is given. Section III presents the existing solution to compensate loss of observation in KF. Section IV discusses linear prediction theory wherein linear prediction schemes (NE and LGA) are discussed. The third linear prediction technique, LDA is not discussed in this paper in order to focus attention on the core contribution of implementing LerouxGueguen Algorithm. In Section V, a numerical example of MSD system,its dynamics and also simulation and results are shown. The paper is concluded with suggestions in the last section.

II. Discrete Time Kalman Filtering

Consider following discrete LTI system

$$x_{k+1} = Ax_k + Bu_k + w_k \quad (1)$$
$$z_k = Cx_k + v_k \quad (2)$$

In the above equations, $k \in R = \{0,1,2,.....\}$ is the discrete time instant, $x \in R^l$ is the input signal, z is the measurement noise, v is the sensor noise, $A \in R^{nxn}$ is the state transition matrix, $B \in R^{nxl}$ is the input matrix, $C \in R^{mxn}$ is the output matrix and (x_0, w_k, v_k) and uncorrelated Gaussian white noise sequences with mean (x_0, 0, 0) and covariance (P_0, Q_k, R_k).

Algorithm 1: Basic Kalman filter

1. Initialize
   $x_{0|0}, u_0, w_0, v_0 P_{0|0}$ and $k = 1$
2. Prediction step
   $x_{k+1|k} = Ax_{k|k} + Bu_k$; State estimation
   $P_{k+1|k} = AP_{k|k}A^T + Q_k$;Covariance Estimation
3. Update of Time-step
   $$k \rightarrow (k+1)$$
4. Observation Obtained
   $$z_{k+1|k} = Cx_{k+1} - v_{k+1}$$
   Compute the innovation vector
   $$r_{k+1|k} = z_{k+1} - Cx_{k+1|k}$$
   Compute the innovation Cov. Matrix
   $$S_{k+1|k} = CP_{k+1|k}C^T + R_{k+1}$$
   Compute the Kalman filter gain equation
   $$k_{k+1} = P_{k+1|k}C^T S^{-1}{}_{k+1}$$
5. Update cycle
   $x_{k+1|k+1} = x_{k+1|k} + k_{k+1}r_{k+1}$; state Estimation
   $P_{k+1|k+1} = (1 - k_{k+1}C)P_{k+1|k}$; Cov.Estimation
6. Return to step 2

The estimation through Kalman filter is summarized in the Algorithm 1. From the above Algorithm it is easy to realize the update step is totally dependent on measurements. When output data (z_k) is unavailable, Kalman filter may not result in optimal estimation. In such a situation, we used three different linear prediction methods for compensating the missing output for update step.

III. Open Loop Kalman Filtering

In simple words, in OLE when measurement data is not available the Kalman filter gain is set to zero, which means that no update cycle is carried out as long as data is unavailable. Only prediction step is performed repeatedly, and when the data reoccurs update step will be executed. In OLKF, prediction is referred as "estimation" [xiii]. OLE has simpler structure, so it takes much less time in estimation, but it has some disadvantages, which are given below.

1) OLE technique may diverge in practice when data loss occurs for long time and it is likely that error covariance could exceed the limit/bounds if the upper and lower bounds of error covariance are provided [viii].
2) When measured data becomes available after the loss period, oscillations and/or sharp spikes can be observed in the estimated parameters [xiii].
3) The steady state values of state and covariance are not regained even after recovery of data loss. It takes too longer to approach the steady state [xiv].

Open-Loop Estimation algorithm is summarized as follows.

Algorithm 2: Open Loop KF

1. Initialize
   $x_{0|0}, u_0, w_k, v_k P_{0|0}$ and $k = 1$
2. Prediction cycle
   $x_{k+1|k} = Ax_{k|k} + Bu_k$; state estimation
   $P_{k+1|k} = AP_{k|k}A^T + Q_k$; Cov. Estimation
3. Time step update
   $$k \rightarrow (k+1);$$
4. Observation Obtained
   z_{k+1} is not available
   There is no residual innovation and hence Kalman gain is not calculated.
   $x_{k+1|k+1} \leftarrow x_{k+1|k}$; State Estimation
   $P_{k+1|k+1} \leftarrow P_{k+1|k}$; Cov.Estimation

5. Return to step 2

Due to the aforementioned limitations, a robust technique is required to improve estimation with limited error covariance in case of data loss. In order to suit the problem of data loss, the existing linear prediction methods [i] are amended by providing minimum mean square error based algorithm that decides the upper bound of filter order.

IV. Linear Prediction Methods

According to linear prediction theory the future values of a discrete time signal are estimated as a Linear combination of the present and past samples of the signal. The missing samples can be reconstructed from its previous *M* samples using the following equation.

$$\bar{z}_k = \sum_{i=1}^{M} \alpha_i z_{k-i} \quad (3)$$

where $\bar{z}_k$ is the measured signal or compensated observation, *M* represents Linear Prediction Filter Order and parameter represents the weights assigned to the previous observations according to their contribution and are known as LPCs. LPCs can be computed using various methods but some optimal methods are Normal Equation, Levinson Durbin Algorithm and LeurouxGeugeun Algorithm. In routine practice, no strategy is available to decide the value of `M` in NE, LDA and LGA. However, some theoretical bound is always required to decide the threshold limit on the value of `M`. Hence, the word "Modified" is frequently adopted to these schemes such as one is shown in Algorithm 3.

Algorithm 3: Choice of the LPFO

1. $Trace E_{max}(k-1) = \max(E_i)$, *where* $E_i = |x_i - \hat{x}_i|_2 \quad i = \{1,2,\dots\ k-1\}$(*state vector*).
2. *Initialization* $n = 1$, *Compute* R_ψ *and* r_ψ.
3. Recursion = 2, ...,M
   Obtain $\bar{z}$ using Equation 3.
   Calculate measurement updated state estimation $\hat{x}_k$ based on this compensated observations.
   Compute $E_n(k) = |x_k - \hat{x}_k|_2$.
   Check Is $E_n(k) \le E_{max}(k-1)$
   Yes $M \leftarrow n$:order of the LP filter
   Otherwise $n \leftarrow n+1$
4. Repeatstep 3.

a. Normal Equation Method

The Normal Equation derivation is actually based on the minimization of the mean square error. In Normal Equation method LPCs α_i are calculated as

$$A_\alpha = r_\varphi R_\varphi^{-1} \quad (4)$$

where

$$R_\varphi = \begin{pmatrix} R_\varphi(0) & R_\varphi(1) & R_\varphi(2) & \cdots & R_\varphi(M-1) \\ R_\varphi(1) & R_\varphi(0) & R_\varphi(1) & \cdots & R_\varphi(M-2) \\ R_\varphi(2) & R_\varphi(1) & R_\varphi(0) & \cdots & R_\varphi(M-3) \\ \vdots & & & \ddots & \vdots \\ R_\varphi(M-1) & R_\varphi(M-2) & R_\varphi(M-3) & \cdots & R_\varphi(0) \end{pmatrix}$$

is the authocorrelated matrix,

$$A_\alpha = [\alpha_1 \quad \alpha_2 \quad \alpha_3 \quad \cdots \quad \alpha_n]^T \quad (5)$$

the desired LPCs array,

$$r_\varphi = [r_\varphi(1) \quad r_\varphi(2) \quad r_\varphi(3) \quad \cdots \quad r_\varphi(M)]^T \quad (6)$$

The autocorrelation array with

$$E(z_{k-i}z_{k-n}) = \begin{Bmatrix} R_\varphi(0) & if\ i = n \\ R_\varphi(|i-n|) & if\ i \neq n \end{Bmatrix} \quad (7)$$

and

$$r_\varphi(n) = E(z_k z_{k-n}) \quad (8)$$

From equation (4), the optimal values of the modified LPCs are computed.

b. Modified LerouxGueguen Algorithm

As discussed before, the earlier schemes, namely OLE, modified NE and modified LDA have their own limitations. Therefore, a strategy is required which could answer to these limitations handsomely. In this paper LerouxGueguen Algorithm has been believed to overcome these limitations. In order to reconstruct the data required in measurement update

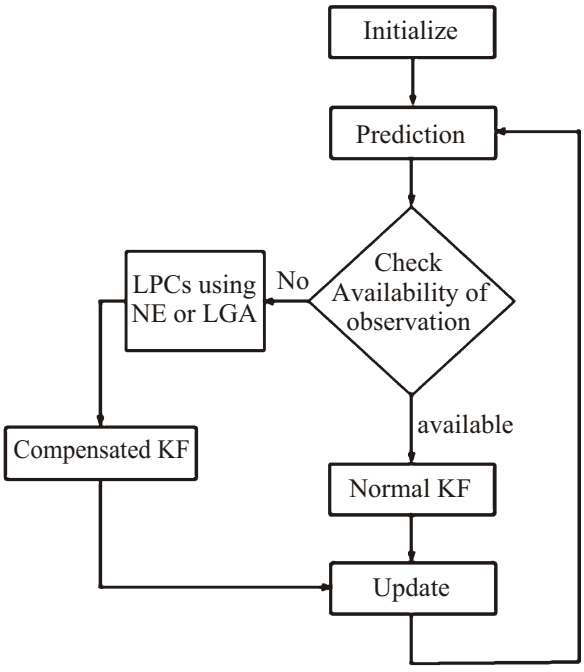

Fig. 1. Flow chart of the proposed scheme

Algorithm 4: Modified Leroux Gueguon Algorithm

1. *Initialization* $x_{0|0}, i = 0;\ \zeta^0[k] = R[k] for\ k = -M + i, \ldots, M$

2. *Threshold Error*
   Set the value of threshold error E_{th}.

3. Recursion i={1,2,3,…, M} where M=LPFO
   3.1 Compute the i^{th} reflection coefficients as
   $$\bar{k}_i = \frac{\zeta^{(i-1)}[i]}{\zeta^{(i-1)}[0]}$$
   Stop when $i = M$.
   3.2 a) Compute the error signal $E_i = |x_i - \hat{x}_i|_2$
   b) Is $E_i \le E_{th}$
   Yes; stop the process **M←I**
   3.3 Compute the values of ζ parameters
   $$\zeta^{(i)}[i] = \varepsilon^{(i-1)}[k] - \bar{k}_i \zeta^{(i-1)}[i-k];$$
   $$K = -M + i + 1, \ldots, 0, \ldots, M$$
   Update $i \leftarrow i + 1$ and
   Repeat Step 3.1

step of Kalman filter, LGA is integrated with the Kalman filtering process. It computes reflection coefficients without dealing directly with LPCs from the autocorrelation matrix. LGA also reduces the computational cost of NE method. A Modified LGA is given in following algorithm.

The values of are used to calculate the LPCs. As the intermediate variables having bounded values so LGA technique depicts better performance in fixed-point environment. LGA has also a problem that it returns only RCs, which is not a major concernif the filter is in lattice form [x]. In order to test the performances of NE and LGA (i.e how better these techniques could reconstruct the data), these schemes are integrated with the conventional Kalman filter as shown in the subsequent section.

In the following section, the theory presented for proposed schemes is tested on a well-known numerical example of Mass-Spring-Damper system.

V. Numerical Example of Mass-Spring-Damper System

The section presents 1) the dynamics of a simple second order mechanical system i.e. Mass-Spring-Damper system and 2) the simulation results for the three under discussion schemes.

A. Dynamic of MSD

In this subsection, a simple second order mechanical system namely Mass-Spring-Damper system is demonstrated. Such systems are commonly control experimental devices frequently encountered in many technical laboratories [xiv].

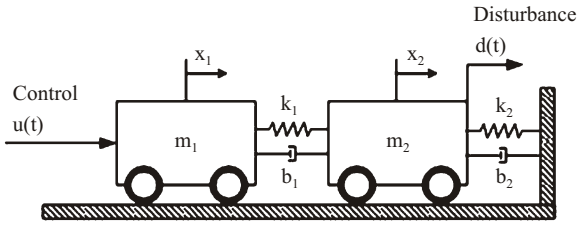

Fig. 2. Mass-Spring-Damper system

In the Fig. 2, *u(t)* is control input, k_1 and k_2 are spring constants, b_1 and b_2 are coefficients of viscous damping, m_1 and m_2 are masses, and x_1 and x_2 are the displacements of masses m_1 and m_2 respectively. The dynamics of MSD system are described by the following mathematical equations:

$$\dot{x}(t) = Ax(t) + Bu(t) + Hw(t)z(t) = Cx(t) + v(t) \quad (9)$$

where the state vector consists of displacement and speed of two masses m_1 and m_2 and is described as

$$x(t) = [x_1(t) \quad x_2(t) \quad v_1(t) \quad v_2(t)]^T$$

and

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ \frac{k_1}{m_1} & \frac{k_1}{m_1} & -\frac{b_1}{m_1} & \frac{b_1}{m_1} \\ \frac{k_1}{m_2} & -\frac{k_1 + k_2}{m_2} & \frac{b_1}{m_1} & -\frac{b_1 + b_2}{m_2} \end{bmatrix}$$

$$B = [0 \quad 0 \quad \frac{1}{m_1} \quad 0]^T$$

$$C = [0 \quad 1 \quad 0 \quad 0]$$

$$H = [0 \quad 0 \quad 0 \quad 3] \quad (10)$$

The MSD system disturbance and sensor noise dynamics are described as *E[w(t)]=0*, *E[v(t)]=0*. By substituting the values of parameters $m_1 = m_2 = 1$, $k_1 = 1$, $k_2 = 0.15$, $b_1 = b_2 = 0.1$ and sampling interval is $T_s = 1ms$. Hence, the above matrices will become

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 1 & -0.1 & 0.1 \\ 0.1 & -1.15 & 0.1 & -0.2 \end{bmatrix}$$

$$B = [0 \quad 0 \quad 1 \quad 0]^T$$

In the subsequent subsection, the OLKF, modified NE and modified LGA are implemented to the above MSD system and results are discussed in the following paras. In the modified NE and LGA schemes, the missing measurement samples are reconstructed by using linear prediction schemes and hence the estimation error is less as compared to OLKF when data loss occurs.

B. Simulation and Results

In the simulations, the results obtained for OLKF, modified NE and LGA with the data loss are compared. The sampling time period is $T_s = 1ms$. Data loss occurs from 2.4 to 2.7 s. In all results, the solid line shows the actual state and the dashed line shows the estimated state.

In Fig. 3, the four associated states are shown for the open-loop scheme along with actual states. It can be seen that during the data loss period, OLE betrays from the actual state track prominently. The data loss region is highlighted in Fig. 4.

This is because, no update step is performed in OLKF in the event of data loss, and therefore it is computationally less expensive. After performing simulation for 100 times on a system Core i3-3110M CPU @ 2.40GHz - 2.40GHz, RAM 2.00GB, 64-bit Operating System; the mean time taken by OLKF is 2.4128 s in case of data loss from 2.3 to 2.8 s.

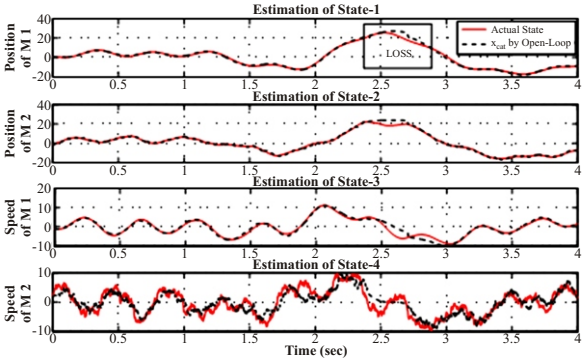

Fig. 3. Performance of Open Loop Estimation

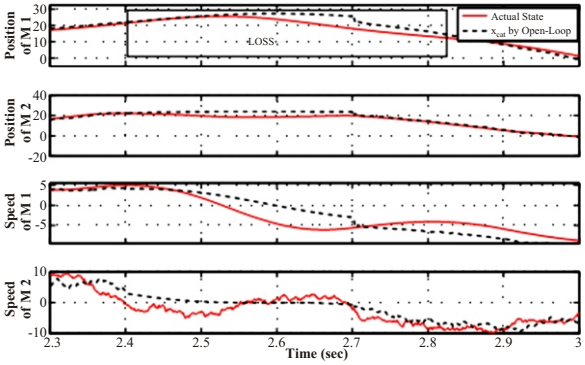

Fig. 4. Highlighted view of data loss region

The estimated four states associated with MSD system are obtained using modified NE method. In order to grasp clear taste of the modified LGA scheme, only 2nd state (for which measurement data is available) has been analyzed in this paper. Its estimation through modified NE method is shown in Fig 5. It can be verified that modified NE method, at the cost of computational efforts, provides better estimation results than OLE scheme.

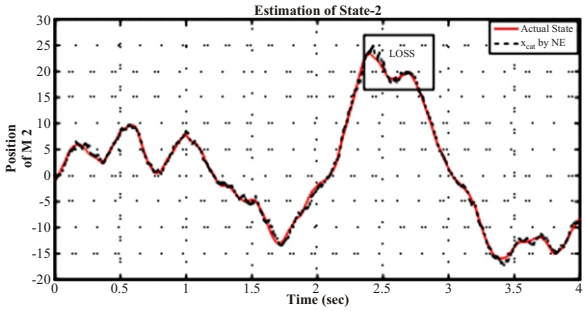

Fig. 5. Estimation of Position for Mass 2 through modified NE

Since in modified NE, the LPCs are computed using inversion of large matrices (of order $M \times M$, where M is decided by Algorithm 3), therefore it is computationally expensive.

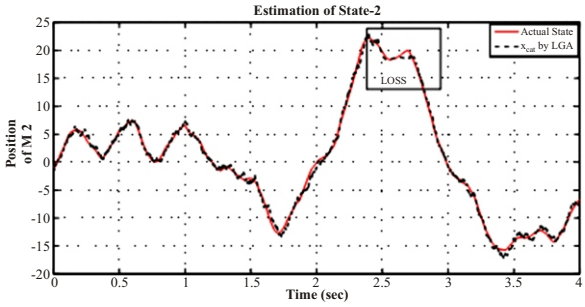

Fig. 6: Performance of LGA

Similarly, the estimation of state 2, shown in Fig. 6, has been achieved using modified LGA, which is the main contribution of this paper. It can be seen that the estimated result (dashed line) of the modified LGA tracks the actual position (solid line) and does not diverge significantly as compared to OLE and modified NE methods. Since LGA avoids the inversion of large matrices, it is computationally inexpensive than NE method. This claim can be verified from Table I. In addition, modified LGA also overcomes the issue of large dynamics range in a fixed point environment which is raised in LDA scheme.

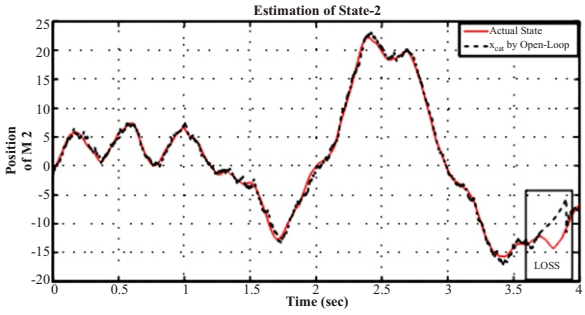

Fig. 7: Open Loop Estimation for data loss from 3.7 3.9 sec

In order to view broader spectrum of modified

scheme, LGA is tested for data loss at various locations. In this connection, Figures 7-11 show the performance of OLE, modified NE and modified LGA scheme respectively.

It has been considered necessary to present error analysis for the three under discussion schemes (OLE, modified NE and modified LGA), Fig. 10 shows the absolute error analysis. Truly speaking, modified NE and LGA provide significantly small error than OLE during the data loss period.

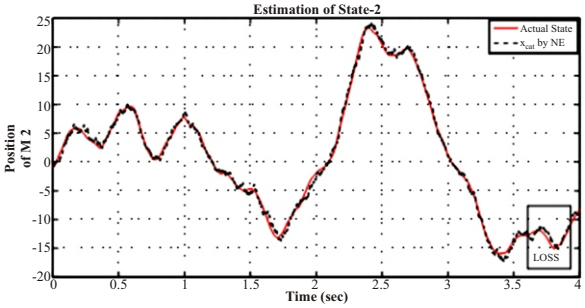

Fig. 8. Estimation through NE for data loss 3.7 - 3.9 sec

Since this paper focuses on the performance of modified LGA method compare to OLE and NE, Table I and Fig. 11 describe the cumulative computational time for modified NE and LGA schemes in tabulated form and graphically. As discussed in previous Figures, OLE abruptly diverges and hence suffers from large errors. Normal Equation method, on the other hand, is computationally expensive. The modified LGA overcomes both of these problems and hence provide better estimation results.

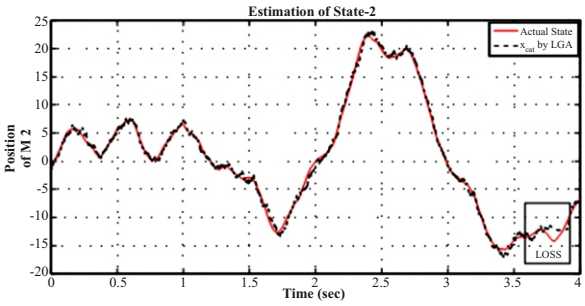

Fig. 9. Performance of LGA for data loss 3.7 3.9 sec

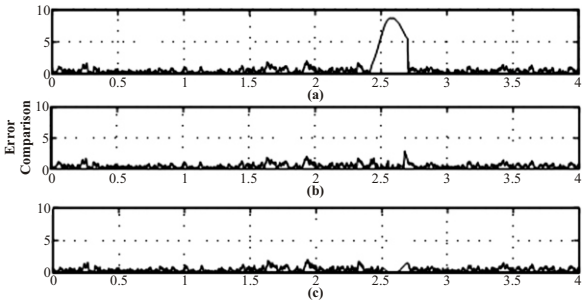

Fig. 10: Error Comparison a) Open-Loop Estimation, b) Modified NE, c) Modified LGA

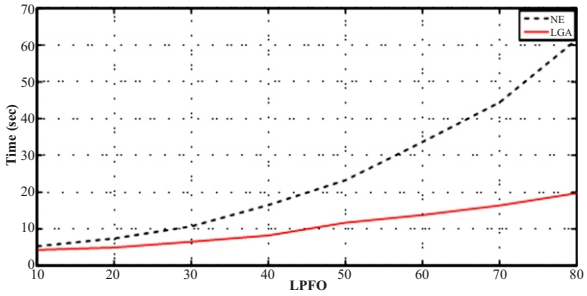

Fig. 11. Computational time comparison of NE and LGA for different LPFO

TABLE I
COMPUTATION ANALYSIS FOR NORMAL EQUATION AND MODIFIED LGA

LPFO	Comp. Time for NE (s)	Comp. Time for LGA (s)
10	5.2833	4.2774
20	7.3977	4.9342
30	10.6921	6.5057
40	16.4922	8.2134
50	23.2320	11.6752
60	33.6234	13.7644
70	44.3985	16.3645
80	61.6001	19.7254

VI. CONCLUSION

Earlier methods adopted to deal data loss scenarios in state estimation have shortcomings such as more computational time and large errors. OLKF takes much less time but it has unbounded error. Alternatively NE method reduces the error but it takes more computational time in calculating LPCs. In this paper, a modified version of a particular Linear Prediction technique namely, LerouxGueguenAlgorithm has been presented to handle these two shortcomings. The proposed scheme avoids the inversion of large matrices, hence is computationally effective. LGA also improves the performance of OLKF by bounding the error during the data loss. A minimum mean square error based criteria is set to decide the order of linear prediction filter. Hence LGA is considered an optimal technique to compute LPCs in case of data loss.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

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