COMPARISON OF DIFFERENT DECLUSTERING PROCEDURES USING PAKISTAN EARTHQUAKE DATASET

BY

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Abstract: *The composite earthquake catalogue is an essential part of seismic hazard assessment. After computing, any previous seismic event can be declared as mainshock from composite earthquake catalogue is known as declustering. This study is a comparison of two declustering methods for Pakistan regional seismicity. This earthquake catalogue consists more than 34000 seismic events from the period 1960 to 2019. First method was Gardener and Knopoff 1974 contained about 2714 clusters were found after declustering, a total of 19512 (57.19%) events out of 34112. Practically 14600 events are found to be declustered. 2nd method was Uhrhammer 1986 was used in which 2599 clustered were found and among the total declustered events were 16540 (53.13%) out of 34112. Comparatively Gardener and Knopoff and Uhrhammer procedures were almost the same, based on time and distance space window. But the reliability of Gardener and Knopoff is almost 4 % more accurate than Uhrhammer. Therefore, to determine the g value at any specific location and other earthquake engineering parameters Gardener and Knopoff method for declustering is more effective than the other methods. Seismicity maps were also drawn for declustered and clustered distribution. Proportional outcomes explained these two mathematical expression. Conclusively, Gardener and Knopoff method is reliable, effective and authentic for deculstering procedures for seismicity data and this method is likely better than the Uhrhammer and other procedures*

INTRODUCTION

Earthquake seismology is a bridge between geology and geophysics. This connection is based on the earthquake catalogue. Earthquake data base contained information regarding earthquake epicenter, magnitude, depth and wave phases which are very important to explore the earth interior. Seismologist, geophysicist and geologist all are using seismic waves to analyze the earth interior. Seismicity pattern can also help to understand the earthquake scenario about forecasting. For this purpose, most important thing is the arrangement of earthquake catalogue either clustered or declustered. In fact, earthquakes are connected with spatial and temporal phenomena. This theory is already based on the empirical relation proposed by Omori-Ustu (Omori, 1895; Utsu, 1975; Utsu, et. Al., 1995).

Body waves, which travel inside the whole earth body to evaluate the earth internal structure, whereas surface waves are the destructive waves travel along the surface of earth (Sherif, 2016). Earthquake is natural disaster and we couldn't predict before time. On the other hand, forecasting is a process which able to forecast a seismic event in long term scenario. Earthquake data based contained the information about epicentral location and moment magnitude. The preparation and arrangement of earthquake databased is not an easy task. But some nation and International online source have their broader online sources for earthquake events after this we could be organized in well define catalogue. Waveform is also part of this data base. Many softwares and applications online are available to pick the depth phase and other waveform information. Online earthquake catalogue is not in proper form nor it will use in any process of seismic hazard analysis. Earthquake data base contained may duplicate events, aftershocks, main shocks and foreshocks. To rectify this catalogue to obtaining the mainshock without any duplication we do declustering (Kagan and Jackson, 2012). Termination of duplicate events, dependent / aftershocks as well as foreshock in earthquake catalogue is complicated process in earthquake seismology (Kanamori 1977; Leun and Stark, 2012). In all around the world many earthquakes recorded agency, published papers,

seismic network station and reports as well as article have been published on the seismicity of any region. Heterogeneous distribution of magnitude, specious depth estimation, and deviation in seismic data leads to wrong information during research study (Teng and Baker, 2019). Many researchers have their own methods for declustering earthquake catalogue which are based on time and distance space window (Stiphout et. al., 2012). In the field of seismology, these methods are widely used according their scenario and liability of data and source parameters (Weimer 2000). Some are most useful procedures for earthquake declustering defined by Uhrhammer (1986), Knopoff-Gardener (1972), Gardener-Knopoff (1974) Reasenberg (1985) and Grunthal et al., (2009). Statistical analysis of seismicity and their parameters can be explored using ZMAP. This is a complete suite to evaluate the earthquake source parameters. ZMAP is a graphic user interface (GUI) developed in MATLAB (Weimer, 2000). A complete composite earthquake dataset contained more than 34000 events of Pakistan was arranged from Jan 1960 to Dec. 2019. The seismicity distribution map was drawn in Fig.1 where the homogenous scattering of seismic events can be seen with moment magnitude (M_w). Green area shows that Hindu Kush region including Gilgit Baltistan has intense seismicity due to active tectonic features. This research article is a comparison between two different declustering procedures for earthquake catalogue utilizing earthquake data set of Pakistan as case study.

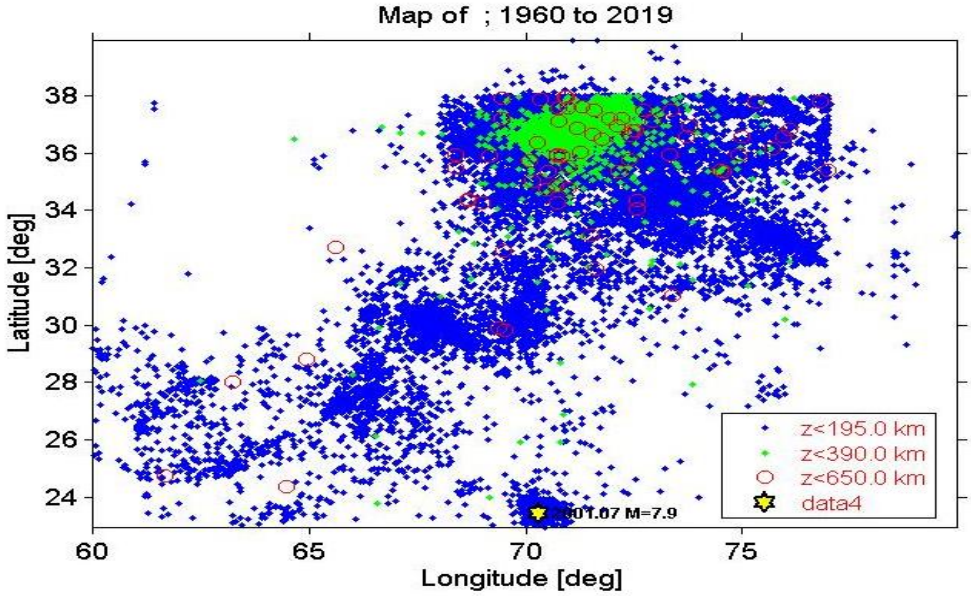

Fig. 1 Seismicity distribution in and around Pakistan region.

CHARACTERISTICS OF EARTHQUAKE CATALOGUE

Magnitude depth correlation

Normally large seismic events happen at shallow depth whereas deeper earthquakes occur at depths down to more than 200 km in earth's crust. The crustal part of the earth is more stiff with high modulus of rigidity contained many faults and folds systems (Zaliapin and Ben-Zion, 2013). Explaining the characteristics of earthquake catalogue, the magnitude and focal depth chart has been plotted in Fig. 2 which shows that the frequency of intermediate depth earthquakes are more than shallow depth earthquakes.

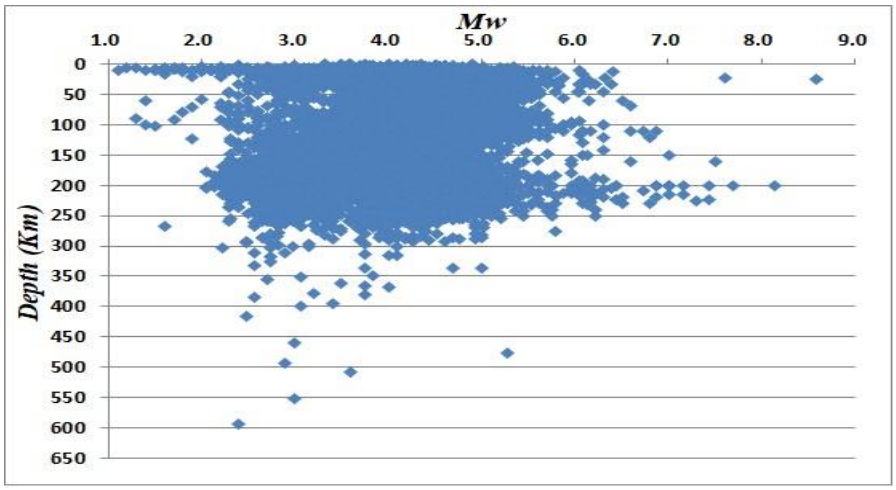

Fig. 2 Correlation between depth and magnitude of earthquake data base.

CORRELATION OF MAGNITUDE, DEPTH AND PERIOD

It is well known that earthquake catalogue contained a lot of information. Fig. 3 describe the correlation between different parameters. The frequency of earthquakes of magnitudes3.0 – 5.5 is higher as compared to other magnitude (Fig. 3a). In Fig. 3b at shallow depth maximum numbers of earthquake can be seen. Periodically maximum numbers of seismic event occur in the period from 2000 to 2019 (Fig. 3c) which is due to active fault and fold system in some specific active region. Active tectonic setting in and around this region is a big cause to generate the low magnitude seismic events. This is the reason to increase the seismicity rate. In Fig. 3d a combine version of magnitude, depth and time period explained shallow, intermediate and deep earthquakes with respect to their magnitude over the time period.

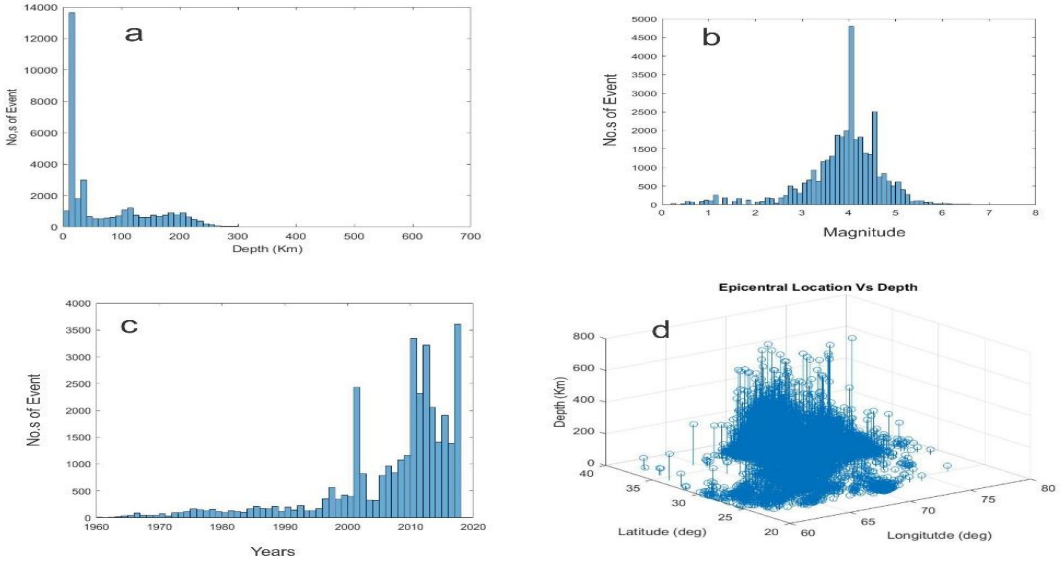

Fig. 3 Correlation between earthquake catalogue columns

MATERIALS AND METHODS

A complete catalogue was prepared which contained foci, magnitude, depth and time. More than 30,000 events from 1960 to December 2019 were taken from different online earthquake data sources

specifically Pakistan Seismic Monitoring Network (PSMN). These seismic events tectonically distributed all over Pakistan. The study region is geographically bounded by latitude 20^0-40^0 N and longitude 60^0-80^0 E.

The most useful product to study the tectonic settings of any region is earthquake catalogue. In this current period advanced seismograph have much capacity to record thousands of the seismic events over the year. ZMAP is a product of tools to analyses the seismicity and detail study of fault parameters as well as crust deformation mapping (Weimer and Wyss, 2000)

Throughout the study of earthquake seismology, clustering of data first time used by Aki 1956 and 1965) to determine that either it is Poissonian or not? In Initial analysis it was inferred that study it is infer that earthquake catalogue is not accurate for Poisson distribution. They tried to decluster the seismic event using different algorithm excluding aftershocks and foreshocks. In this study Gardener and Knopoff (1974) designed a window based method for declustering in which they proposed that aftershocks located as succeeding shocks within specified distance and particular time interval. Declustering process also define the zoning based seismicity with respect to rate of earthquake productivity (Karimiparidari et al., 2013). Same as in the case of foreshocks, succeeding foreshocks generate a large magnitude earthquake that will be treated as large aftershocks. If the catalogue contained the high rate of seismicity such as a comprehensive earthquake catalogue, it is essential to declustered them. Both methods are presented in Table 1 with respect to their time and distance space windows.

Table.1 Mathematical expression of two declustering methods

Method	Distance (d) (km)	Time (day)
Gardener and Knopoff (1974)	$10^{0.1238M+0.983}$	$10^{0.032*M+2.7389100}$ if $M \geq 6.5$ *Else* $10^{0.5409*M-0.547)}$
Uhrhammer (1986)	$10^{1.77+(0.037+1.02M)2}$	$10^{-(3.95+(0.62+17.32*M)2))}$ if $M \geq 6.5$ *Else* $10^{2.88+0.024*M}$

RESULTS AND DISCUSSION

Two methods have been compared to determine the variation in declustering process. One is Gardner and Knopoff (1974) and other is Uhrhammer (1984). According to the GK (1974) method, declustering is based on time space and distance window in which foreshock and aftershock marked under brown line (Fig. 4). Aftershocks were identified if M_w=*4.5* occurs and same magnitude earthquake occurs repeatedly within 45 days in radius of 18 km epicentral distance the it may be marked as an aftershock of earlier earthquake. Similarly, if the event of M_w= *7.5* occurred and same magnitude earthquake comes again within the range of 149 km radius in 680 days then again it will be aftershocks of the previous seismic event. The continuation of same steps, the whole data will be declustered after bundle of clustered events. Using this process, almost 2714 clusters of earthquake have been found. As per algorithm of GK (1974) distance and time window mentioned in blue dots are the declustered events. After identifying the declustered events from earthquake catalogue, a map was drawn by ZMAP as output for declustered events specified by magenta

pluses in color in Fig. 5 are also called mainshocks of remaining earthquake catalogue.

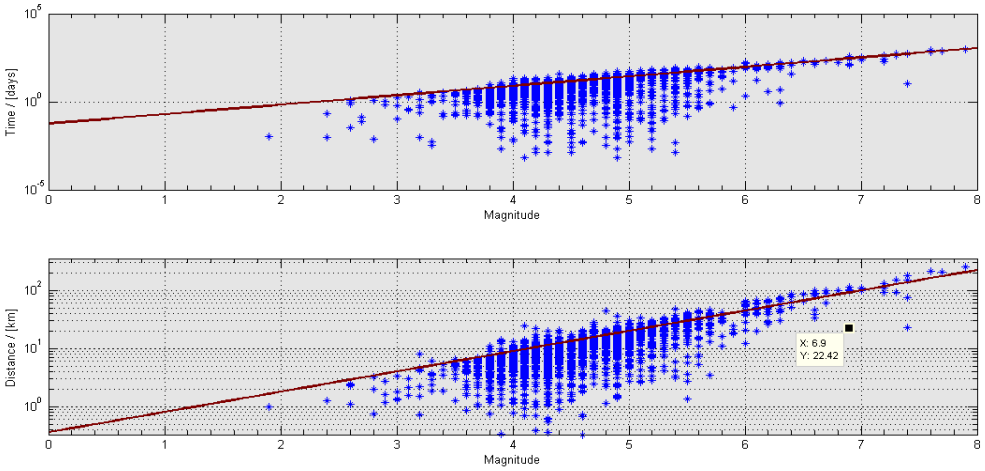

Fig. 4 Time and distance space window for GK (1974) (Khurram and Khalid, 2021)

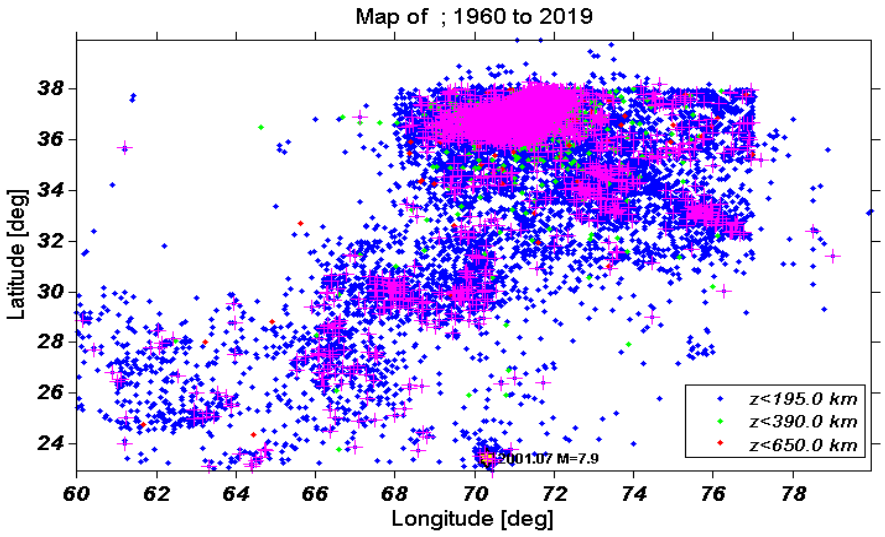

Fig. 5 Remaining clustered events (mainshocks) as pluses sign displaying in magenta pluses color using window method (GK 1974).

Uhrhammer (1986) method is also based on time and distance window with different mathematical expression given in Table 1. This method also linked with clustered seismic events according to the temporal and spatial active zones. Uhrhammer (1986) method explained algorithm of the previous work done by Gardener and Knopoff. The temporal and spatial window using Uhrhammer (1986) method was drawn in Fig. 6 in which magenta pluses indicates the declustered events among the 34112 earthquake events.

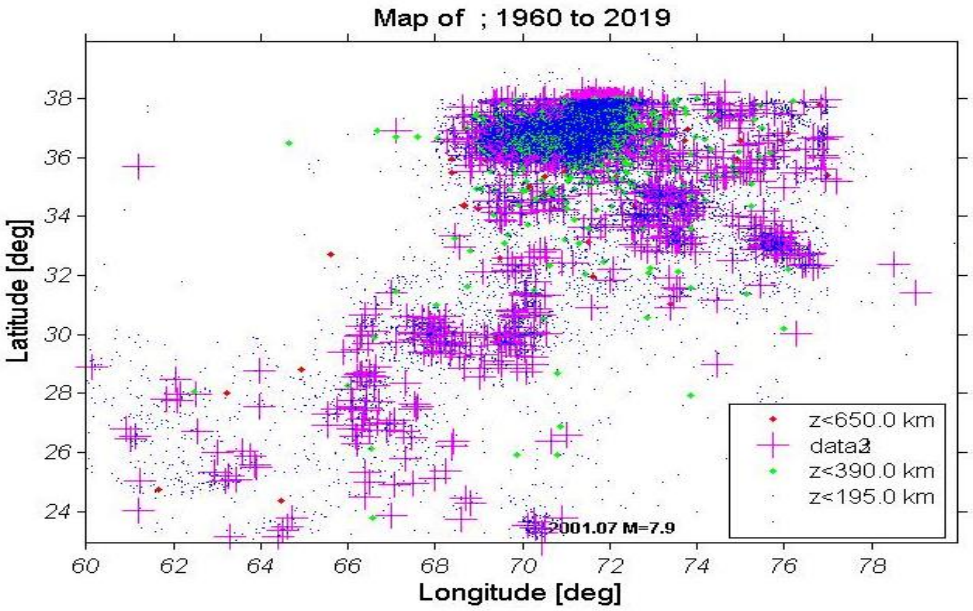

Fig. 6 Spatial and temporal window using Uhrhammer (1986) method for declustering. Magenta pluses signs showing the declustered events.

Comparative analysis has been carried out between two declustering methods given in Table 2. Total 34112 seismic events declustered by GK (1974) and Uhrhammer (1986) procedures were selected to determine the mainshocks and aftershocks. Spatial and temporal mapping of these two methods have already been displayed. Tabular values indicate that efficiency of GK (1974) method of declustered events is high as compare to Uhrhammer 57.19% of total catalogue was declustered whereas in Uhrhammer method only 48.48% catalogue was declustered.

Table. 2 Results differentiation between two declustering procedures

Method	Total Events	Output			
		Clustered	Declustered Events	%	Remarks
Gardener and Knopoff 1974	34112	2714	14600	57.19	Reliable. Successful attempt more dependent events recognized comparatively.
Uhrhammer 1984		2599	16540	48.48	Reliable but it is modified form of GK 1974 method. Not much better comparatively

CONCLUSION

Time and distance space window is a simple way to terminate the foreshocks and aftershocks A composite earthquake catalogue was prepared from 1960-2019 with homogenous moment magnitude M_w

to determine the dependent / sub sequent shocks. This catalogue contained more than 30,000 events. Geographically the study region is bounded by Lat 24^0 - 38^0 and Long 60^0 - 78^0 included Pakistan. Two method were adopted to quantify the declustering from clustered events. Gardener and Knopoff (1974) and Uhrhammer (1986) procedures had been utilized for this study. According to the GK 1974 2714 clustered was detected in which total 19512 events were declustered out of total seismic events 34112 (57.19%) whereas using Uhrhammer (1986) process 16540 declustered events were found out of 34112(53.13%). Comparatively Gardener and Knopoff and Uhrhammer procedures was almost same, based on time and distance space window. However, the reliability of Gardener and Knopoff is almost 4 % more than Uhrhammer. Therefore, GK (1974) method is significant to generate a sequence of mainshocks which is declustering property towards predictability for g value of peak ground acceleration.

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