BIBECHANA

ISSN 2091-0762 (Print), 2382-5340 (Online)
Journal homepage: http://nepjol.info/index.php/BIBECHANA
Publisher: Department of Physics, Mahendra Morang A.M. Campus, TU, Biratnagar, Nepal

Use of geometric Brownian motion to forecast stock market scenario using post covid-19 NEPSE index

Prabin Thapa*, Binil Aryal**
Central Department of Physics, Tribhuvan University, Kirtipur
*Email: physicpract@gmail.com
**Email: binil.aryal@cdp.tu.edu.np

Article Information:
Received: September 13, 2020
Accepted: February 25, 2021

Keywords:
Stochastic process
Geometric Brownian motion
NEPSE Index
Python simulation

ABSTRACT

Stock market is one of the fields where the randomness is prominent factor to be considered. Although many stochastic processes deal which the randomness found in nature through the interdisciplinary subject like Econophysics, many of them exhibits cumbersome trends. So, Geometric Brownian motion (GBM) is used to analyze the market scenario of Nepal on the basis of the parameter; NEPSE Index along with the prediction of indices through python programming platform. Python simulation was carried out to check the consistency by implying it to the stable market timeline 2003/2004. And after the verification of the model proposed in the stable market year, the model (GBM) is employed to the unstable timeline; pandemic situation by COVID-19 in 2020. Mapping of Nepal stock market through GBM was found to be consistent with the standard forecasting accuracy making GBM one of the flexible and consistent to predict stock market scenario of Nepal accounting the random nature.

DOI: https://doi.org/10.3126/bibechana.v18i2.31180

1. Introduction

Stock Market

Stock generally referred as equities or equity securities of any company or corporation determines the share in the ownership of esteemed company or corporation. Stocks are mainly divided into two: public stock in which public are allowed taking certain portion of corporation securities or ownership through investment and private stock which is owned by private companies and sold only to investors. And the market facilitating the sales and purchase of this ownership among individuals, companies and investors is share market [1]. There are many indicators to measure the status of stock market, one of them is the stock index; in the context of Nepal, Nepal Stock Exchange (NEPSE) Index which indicates the increase or decrease of total market capitalization of companies' transactions that are enlisted in Nepal Stock Exchange. This indicates the increase or decrease of overall market; therefore, it has significant importance to investors.

Factors affecting Stock Market

The attractiveness of stock price is affected by several factors that results in the inconsistency or the randomness in the stock index. Some of them are:

- The After-Hours Trading (AHT) where the trading between the closing bell of present day and opening bell of next day fluctuates the value of stock price.
- Sudden news about companies listed in share market during non-trading period.
- Political condition, natural calamities, epidemic and pandemic and many others.

From above it can be said that figuratively stock market has the random nature inherent in it [1, 2]. So, modeling of such random nature of stock market needs to be accounted that is where stochastic process comes into play which shows the connection between physics and economics [3].

Stochastic process

Stochastic process is a process where there are observations at the certain times and the outcomes or the observed values at each time has the randomness inherent in them; random variable. In terms of probability concept, there is a certain probability to acquire certain outcome and that probability depends upon the previously obtained observations [4]. This means that more the observations, more accuracy the stochastic process addresses to the outcome. But generally, such processes are cumbersome and become difficult to treat in long run. So, different simplified stochastic processes are proposed over time in the field of Econophysics like Markov process, Step process. Levy process, Random walk, Weiner process, Brownian motion etc. [4, 5].

Brownian motion

Brownian motion generally referred as the motion defined by a particle (Brownian particle) suspended in a liquid where the particle is small enough to be influenced by the underlying molecular motion. Such types of motion of small particles in liquid demonstrate dissipation and fluctuation. Moreover, the motion is governed by two kinds of force; the systematic force which is responsible for damping by an exchange of energy and momentum between Brownian particle and molecules of liquid, providing dissipation and the force by the irregular interactions from the collision between Brownian particles and molecules of liquid may change the direction and velocity of Brownian particles providing fluctuation in the system. In spite of dissipation and fluctuation, diffusion; an irregular way Brownian particle is spread out in the system gives the concept of diffusion constant [4].

The Brownian particle can also be influenced by external factors like presence of charged ions, presence of electric fields, temperature, pressure etc.

Geometric Brownian motion (GBM)

Geometric Brownian motion is continuous-time stochastic process also referred as Wiener process with drift. It is the most used model for mathematical finance in modeling stock prices [4].

For stochastic process $X\ (t)$ to follow GBM, it satisfies stochastic differential equation (SDE) as [5-8]

$$dX(t) = \mu X(t)dt + \sigma X(t)dB(t) \qquad (1)$$

where $B(t)$ represents the Wiener process or Brownian motion μ represents drift accounting for deterministic trend σ represents volatility accounting for unpredictable events Under Itô's interpretation [5], for arbitrary initial value X_0 the equation has the analytic solution

$$X_T = X_0 e^{\left(\mu - \frac{1}{2}\sigma^2\right)T + B_T} \qquad (2)$$

With the incorporation of such deterministic trend and unpredictable events in Geometric Brownian motion [9], it is well suited for modeling of stock market.

2. Materials and Methods

Modeling of stock market

The prediction of Nepal Stock market scenario on the basis of NEPSE Index using Brownian notion is python simulation-based work. So, to use Brownian motion in stock market we make appropriate analogy between Brownian motion and stock market parameters.

X_0 = Initial NEPSE Index which in our case is the last date NEPSE Index of our historical data.

dt = Increment in time (For our case one day) As the NEPSE index of the day is published in every one day. dt =1day.

T = length of our prediction horizon, in our case it is 22 days as trading days is only 22 days with the exclusion of weekend.

N = Number of time points in the prediction time horizon = T/dt

μ = Mean return of NEPSE Index i.e.

$$\mu = \frac{1}{Total\ Days(N)} \sum_{k=1}^{N} \frac{X_k - X_{k-1}}{X_k} \tag{3}$$

σ = Standard deviation of historical daily return-index

$$\sigma = \sqrt{\frac{1}{N} \sum_{k=1}^{N} (X_k - \mu)^2} \tag{4}$$

B = Brownian increment which follows normal distribution with mean zero and variance equal to interval of time in our case it is one as dt = 1day.

Drift: Drift reflects the longer-term trend in stock index. They have constant value calculated from the historical data set.

$$Drift = \mu - \frac{1}{2}\sigma^2 \tag{5}$$

Note: If we keep applying drift without any random shock the stock price smoothly goes up for positive drift and smoothly goes down for negative drift. So, the stock price is non-zero due to drift.

Diffusion: Diffusion consists of the short-term fluctuations so it consists of the variable B_k which contains random shock information.

$$Diffusion = \sigma B_k \tag{6}$$

Algorithm

Step 1: Select the historical data set when the market is pretty stable.

Step 2: Calculate drift and diffusion coefficient from the historical data set.

Step 3: Predict NEPSE Index for certain period using the simulation model.

Step 4: Compare actual Index and predicted one; is it consistent with MAPE (Mean Absolute Percentage Error) table.

Step 5: If the prediction is consistent with MAPE then apply the simulation model for prediction when the market is not stable enough.

Step 6: If the prediction is inconsistent with MAPE then search for the parameterization of the model for making it consistent and GOTO step 1.

Simulation set up

Stock market scenario was simulated for two different scenarios. First, for the stable market year which in our case is the year 2003/2004 where there is no sudden change in the political situation of Nepal, less closing of market in business days and less external factors to affect market. We took historical NEPSE Index data from July 17 2003 to June 15 2004 for the prediction of scenario of market from June 16 2004 to July 15 2004. We simulated one thousand possible market scenarios for this prediction time and tabulated them for percentile calculation. Calculating the percentile for k values: 0.01 (predicted decreasing index), 0.50 (predicted stable index) and 0.99 (predicted increasing index), the three scenarios were deducted from the thousand simulated scenarios. Considering all the scenario of that time line of Nepal, out of three, one scenario was selected and made comparison with the standard table of forecasting.

Table I: A scale of judgment of forecast accuracy [8].

Absolute Percentage Error	**Judgment of forecasting accuracy**
< 10%	Highly accurate
11% to 20%	Good accurate
21% to 50%	Reasonable Forecast
> 51%	Inaccurate Forecast

On the comparison with the standard table for forecasting, the simulation outcome yielded error less than 10 percentages. So, we adopted that the simulation must be sufficient to predict the scenarios for unstable market year. Moreover, best fit for the stable year along with R-squared value was calculated as it also should be consistent with the next simulation which in our case is for the year 2020.

3. Results and Discussion

For the stable year 2003/2004

In order to simulate 1000 scenarios for the year 2003/2004 we took into account NEPSE Index from July 17, 2003 to June 15, 2004. The simulation yielded 1000 scenarios from June 16, 2004 to July 15, 2004 as shown in Fig. 1.

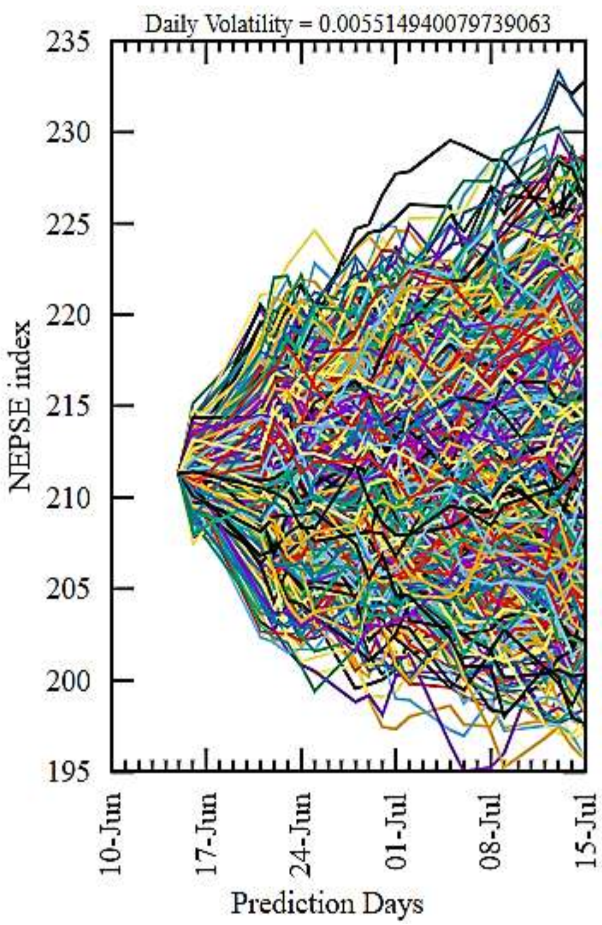


Fig. 1: Thousand possible scenarios of stock market for 2003/2004.

After the percentile calculation, deductions to three scenarios of market from thousand scenarios are able II

Table II: Comparison between predicted indices and actual NEPSE Index for year 2004

Date (D/M)	Predicted Indices			Actual NEPSE Index
	Decreasing	Stable	Increasing	
6/15	211.31	211.31	211.31	211.31
6/16	208.64	211.34	214.18	211.45
6/21	204.54	211.47	218.62	211.51
6/22	203.57	211.24	219.13	213.25
6/23	203.61	211.37	220.02	215.10
6/24	202.62	211.36	220.32	216.51
6/25	202.88	211.48	220.24	217.46
6/28	201.85	211.61	221.60	217.41
6/29	201.40	211.63	222.24	217.72
6/30	201.54	211.65	222.39	218.65
7/1	201.18	211.73	222.86	219.41
7/2	200.83	211.78	222.66	220.75
7/5	200.76	212.08	223.63	225.15
7/6	200.17	212.02	223.68	227.83
7/8	199.69	212.08	225.12	226.88
7/9	199.28	212.19	225.57	226.30
7/12	198.75	212.60	227.34	226.16
7/13	198.57	212.64	227.49	226.42
7/14	198.29	212.66	227.80	226.61
7/15	198.18	212.65	228.12	222.04

We refer the situation of the market in order to select preferred index to represent market. As year 2003/2004 was selected as the stable market period with less inconsistency, we predict that the indices should either increase or remain stable which can also be seen through bar plot. From Fig 2 and Table *II* we can say that out of three predicted indices the increasing predicted index is found to have the close resemblance to actual NEPSE Index for the respective prediction days. Now on selecting the increasing predicted index as our final index we calculate percentage error for the respective days as shown in able III.

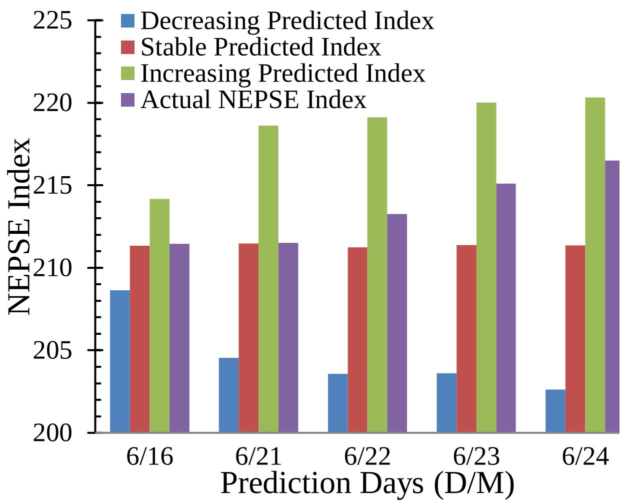


Fig 2: Bar plot of three different scenarios for market year 2004 taking first five dates.

Table III: Error Analysis between selected predicted index and actual NEPSE index for 2004

Date (D/M)	Increasing Predicted Index	Actual NEPSE Index	Percentage Error
6/15	211.31	211.31	0.00
6/16	214.18	211.45	-1.29
6/21	218.62	211.51	-3.36
6/22	219.13	213.25	-2.76
6/23	220.02	215.10	-2.29
6/24	220.32	216.51	-1.76
6/25	220.24	217.46	-1.28
6/28	221.60	217.41	-1.93
6/29	222.24	217.72	-2.08
6/30	222.39	218.65	-1.71
7/1	222.86	219.41	-1.57
7/2	222.66	220.75	-0.86
7/5	223.63	225.15	0.67
7/6	223.68	227.83	1.82
7/8	225.12	226.88	0.78
7/9	225.57	226.30	0.32
7/12	227.34	226.16	-0.52
7/13	227.49	226.42	-0.47
7/14	227.80	226.61	-0.53
7/15	228.12	222.04	-2.74

On comparison with the standard table for forecasting accuracy Table I, we found that our prediction of indices is quite accurate as the error lies below 10%. So, for further discussions we infer best-fit analysis along with R-squared value as in Fig 3.

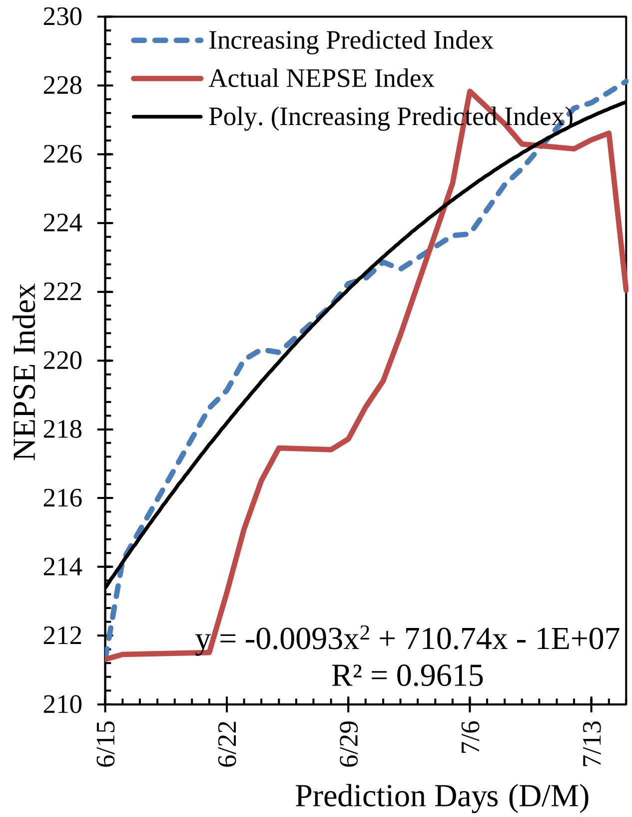


Fig 3: Line plot of selected predicted index and actual index for market year 2004 along with best fit and R-squared value

From the Fig 3 above, it is clear that our model of prediction is consistent and can be applied to other fiscal year of stock market as the R-squared value 0.921 is nearly equal to 1 and the best fit to two degree polynomial shows that the model is capable of including the varying nature of stock market. Moreover, the consistency with the forecast accuracy allows us to imply this model to other market years.

For the year 2020

For the prediction of the current running year, we have taken account of all the historical data i.e. from

2003 to till available date for simulating thousand possible scenarios of market as shown in Fig. 4.

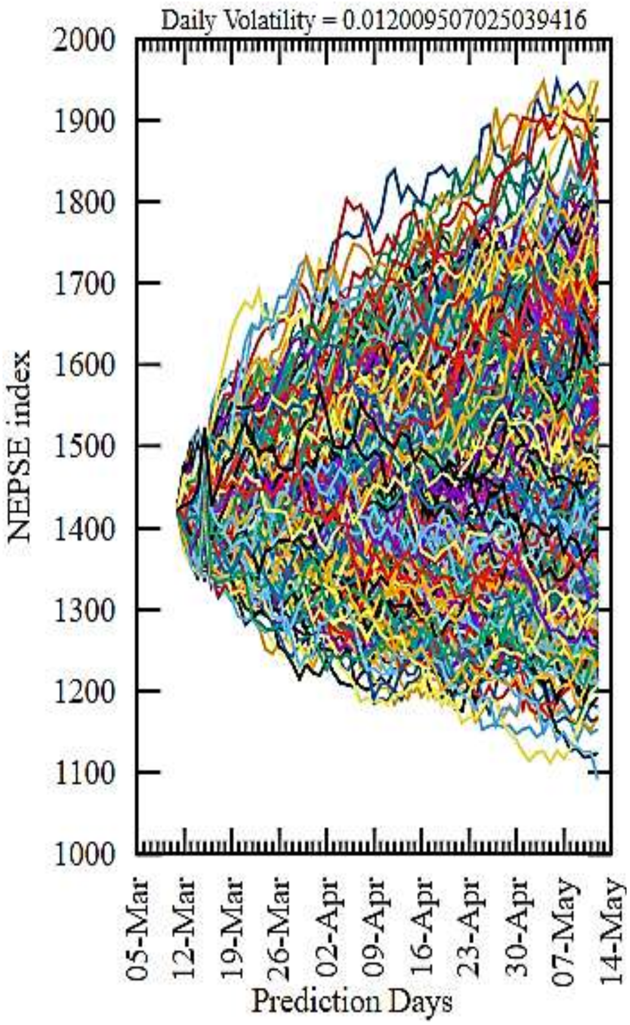


Fig 4: Thousand possible scenarios of stock market for year 2020.

After the percentile calculation, deductions to three scenarios of market from thousand scenarios are shown in table IV.

For the selection among the predicted three indices, we select the decreasing predicted indices due to scenario of year 2020 (pandemic of COVID-19) which can be also seen through bar plot in Fig 5.

On the analysis of Fig 5, we can say that the decreasing predicted index is more convenient to select for representing actual NEPSE index.

Table IV: Comparison between predicted indices and actual NEPSE Index for year 2020.

Date (D/M)	Predicted Indices			Actual NEPSE Index
	Decreasing	Stable	Increasing	
3/11	1423.09	1423.09	1423.09	1423.09
3/12	1384.84	1423.82	1464.31	1377.18
3/15	1348.07	1426.78	1509.26	1313.04
3/16	1346.43	1428.30	1522.36	1316.40
3/17	1342.36	1429.80	1532.88	1272.07
3/18	1337.62	1429.18	1539.36	1255.80
3/19	1332.03	1430.25	1554.57	1269.31
3/22	1314.95	1437.10	1570.07	1251.46
5/12	1208.81	1471.64	1827.46	1226.16

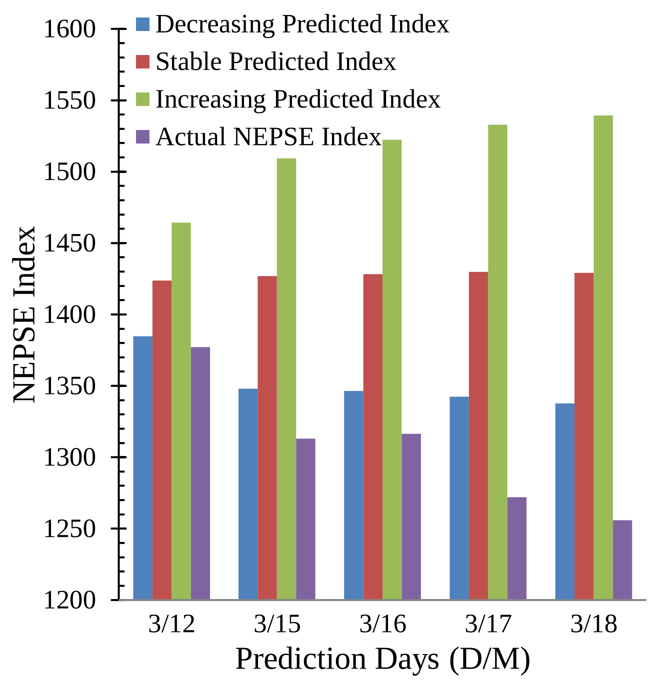


Fig. 5: Bar plot of three different scenarios for market year 2020 taking first five dates.

Comparison with the standard table for forecast accuracy *Table I*, we can see that absolute percentage error is less than 10% which means our prediction is acceptable. The error greater than 4 percentages in *Table V* can be accounted by the following reasoning:

Table V: Comparison between predicted indices and actual NEPSE Index for year 2020.

Dates (D/M)	Decreasing Predicted Index	Actual NEPSE Index	Percentage Error
3/11	1423.09	1423.09	0.00
3/12	1384.84	1377.18	-0.56
3/15	1348.07	1313.04	-2.67
3/16	1346.43	1316.40	-2.28
3/17	1342.36	1272.07	-5.53
3/18	1337.62	1255.80	-6.52
3/19	1332.03	1269.31	-4.94
3/22	1314.95	1251.46	-5.07
5/12	1208.81	1226.16	1.41

1. The opening of the market in weekend (in our case mainly Sunday).
2. The pandemic of COVID-19 worldwide which is responsible for the harsh irregularities in market strategy and situation.
3. Opening of market after 50 days of gap (from March 22 to May 12) made the high impact in prediction as our simulation model is unknown of the sudden close of market.

Then the line plot for the predicted index and actual NEPSE Index along with best-fit as shown in Fig. 6. Although the plot has the best- fit to second degree polynomial, the R-squared value is not as close as that in the year 2003/2004 which can be accounted by the fact the market remained closed for about 50 days which has affected the consistency of having R-squared value nearly equals to one as seen previously in 2003/2004.

Complete Scenario of market in 2020

From Fig 4, we can plot the complete scenario of NEPSE Index up to 12 May 2020 including also the weekend. As we already know that decreasing predicted index is conveying the actual NEPSE Index we can have all the decreasing predicted indices to represent the gap of 50 days when the market was closed. The predicted indices from the date 22 March 2020 to 12 May 2020 is represented Table VI along with line plot in Fig 6.

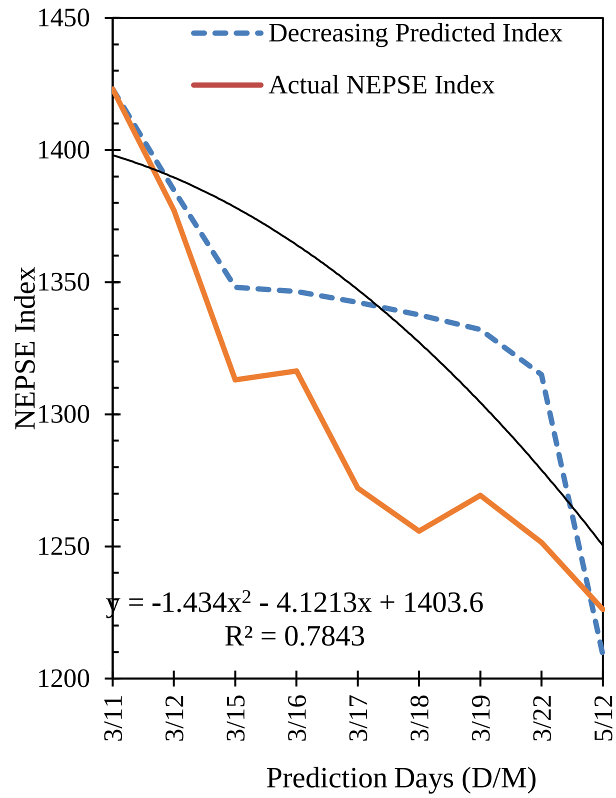


Fig 6: Comparison between selected predicted index and actual index along with best-fit

Now for reliability of prediction we take a look at R-squared value and best fit to two degree polynomial Fig 7 as done for stable market prediction. From the Fig 7 it is clear that the model we have proposed for the stable market scenario is also applicable for other aspects when the market is random. The R-squared value which is 0.936 is nearly equals to 1 meaning the consistency of the model to adopt in stable and non–stable market year.

So far as the part of result and discussion, we have taken two scenarios for stock market analysis; one being the stable stock market (year 2003/2004) and another being the present stock market (year 2020).

Table VI: Predicted index for 50 days gap in 2020.

Prediction Days	Predicted Decreasing Index
Sunday, March 22, 2020	1314.952
Monday, March 23, 2020	1312.675
Tuesday, March 24, 2020	1311.187
Wednesday, March 25, 2020	1292.008
Thursday, March 26, 2020	1294.899
Friday, March 27, 2020	1287.029
Saturday, March 28, 2020	1287.194
Sunday, March 29, 2020	1289.939
Monday, March 30, 2020	1286.990
Tuesday, March 31, 2020	1281.568
Wednesday, April 1, 2020	1275.187
Thursday, April 2, 2020	1277.795
Friday, April 3, 2020	1267.111
Saturday, April 4, 2020	1269.603
Sunday, April 5, 2020	1264.057
Monday, April 6, 2020	1256.732
Tuesday, April 7, 2020	1246.317
Wednesday, April 8, 2020	1247.575
Thursday, April 9, 2020	1251.434
Friday, April 10, 2020	1249.477
Saturday, April 11, 2020	1250.117
Sunday, April 12, 2020	1245.852
Monday, April 13, 2020	1236.393
Tuesday, April 14, 2020	1238.411
Wednesday, April 15, 2020	1240.697
Thursday, April 16, 2020	1239.029
Friday, April 17, 2020	1239.146
Saturday, April 18, 2020	1233.699
Sunday, April 19, 2020	1233.995
Monday, April 20, 2020	1225.443
Tuesday, April 21, 2020	1214.978
Wednesday, April 22, 2020	1220.616
Thursday, April 23, 2020	1222.788
Friday, April 24, 2020	1217.785
Saturday, April 25, 2020	1223.197
Sunday, April 26, 2020	1226.043
Monday, April 27, 2020	1225.471
Tuesday, April 28, 2020	1239.949
Wednesday, April 29, 2020	1232.231
Thursday, April 30, 2020	1234.737
Friday, May 1, 2020	1232.025
Saturday, May 2, 2020	1223.204
Sunday, May 3, 2020	1217.290
Monday, May 4, 2020	1207.588
Tuesday, May 5, 2020	1198.191
Wednesday, May 6, 2020	1188.459
Thursday, May 7, 2020	1205.884
Friday, May 8, 2020	1209.662
Saturday, May 9, 2020	1201.972
Sunday, May 10, 2020	1193.005
Monday, May 11, 2020	1209.513
Tuesday, May 12, 2020	1208.813

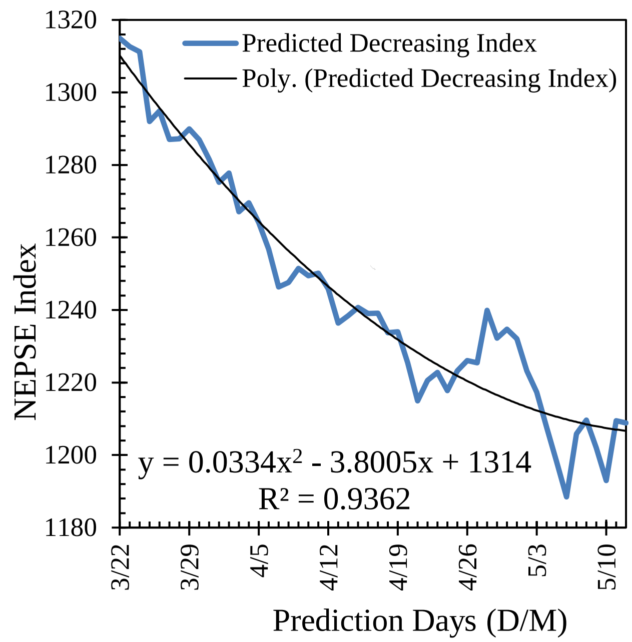
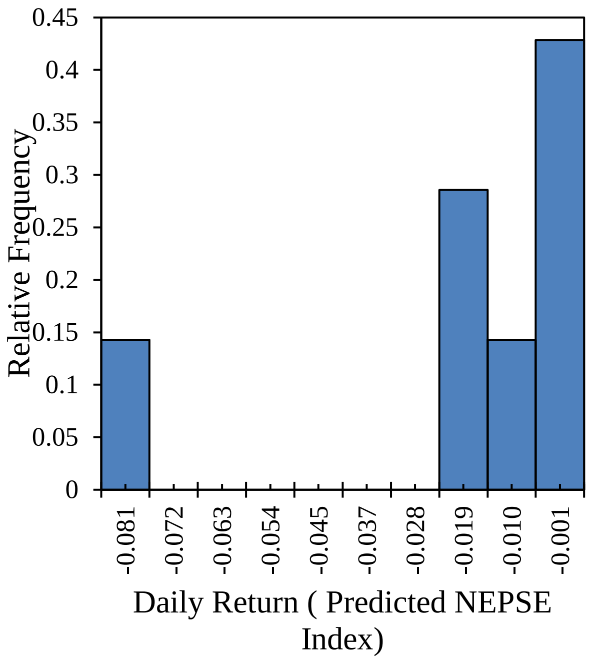


Fig 7: Line plot for predicted (decreasing index) for 50 days gap in 2020 along with best-fit

We tested our Brownian motion model for the stable market at first and after checking its viability shifted to its application in the present date. On doing so we found that the model is applicable to all the scenarios with less than 10% error in each prediction which makes our model more accurate and consistent. The error greater than 3% is accounted by the un-uniformed opening of the stock market like someday the market has opened in Sunday which is globally one of the weekdays when the market should be closed. Moreover, the error in the year 2020 is by the un-uniformity as well as due to the pandemic scenario by COVID-19.

Daily Return Index Analysis



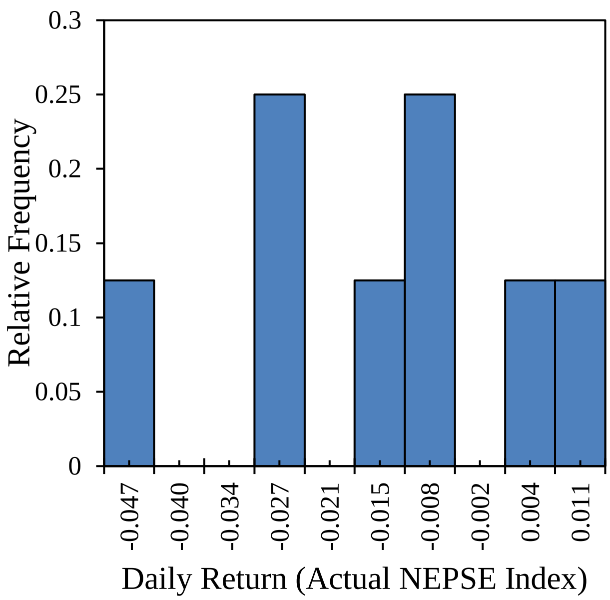


Fig 8: Histogram plot of Daily Returns in terms of NEPSE Index for year 2020 using 10 bins.

Table VII: Table for the Daily Return Calculation of Predicted and Actual NEPSE Index for year 2020. (Refer **Table V**).

NEPSE Index		**Daily Return of NEPSE Index**	
Predicted	Actual	Predicted	Actual
1423.09	1423.09	-	-
1384.84	1377.18	-0.03	-0.03
1348.07	1313.04	-0.03	-0.05
1346.43	1316.40	0.00	0.00
1342.36	1272.07	0.00	-0.03
1337.62	1255.80	0.00	-0.01
1332.03	1269.31	0.00	0.01
1314.95	1251.46	-0.01	-0.01

From Table VII it can be annotated that the trend for the daily return between the predicted NEPSE Index and Actual NEPSE Index for the year 2020 is merely the same indicating better viability of our simulation. Moreover, from Fig 7 it can be seen that the plotting of relative frequencies of daily return of Index making 10 bins, the Gaussian distribution is followed. The histogram for predicted index has half Gaussian as we are selecting only the decreasing predicted index for the year 2020.

Quartile Risk Analysis or Value at Risk (VaR)

Table VIII: Table for the calculation of VaR or Quartile Risk.

Days	**Daily Return of Predicted NEPSE Index**	**Variance**	**Standard Deviation (b)**
3/11	-		
3/12	-0.03		
3/15	-0.03		
3/16	0.00		
3/17	0.00	0.18	0.42
3/18	0.00		
3/19	0.00		
3/22	-0.01		
5/12	-0.08		

From Table VIII it can be seen that the predicted NEPSE Index for the year 2020 has the volatility of 0.42.

Table IX: Table for calculation of VaR at different confidence level.
For
Initial NEPSE Index (a)= 1423.09
Standard Deviation (b) = 0.42
Trading Days (c) = 8 (at May 12,2020)

Confidence Level	Stress Event (d)	VaR (a*b*d*sqrt(c/252)
0.99	2.33	250.02
0.95	1.64	176.78
0.90	1.28	137.73

From Table VII the Value at Risk (VaR) at different confidence level can be seen. At 0.99 confidence level the initial index has the risk of 265.19 giving out (1423.09-250.02) = 1173.07 NEPSE Index (at May 12, 2020) which on comparison to Actual NEPSE Index gives an error percentage of 4.33% which is again consistent with the table of forecast Table I.

4. Conclusion

The simulation of thousands possible scenarios of stock market on the basis of NEPSE index has been carried out using python simulation. On doing so the proposed model is found to be consistent for the analysis and prediction of Nepal Stock market scenario with error persistent with standard table of forecasting.

The conclusions that can be drawn from the results encountered are enlisted as:

1. The predicted model for the stable period of market (2003/2004) shows two degree polynomial fit with R-squared value nearly equals to one. From this it can be known that the proposed model incorporates the changing nature of stock market.
2. Comparison of predicted indices and actual indices shows the error less than 10 percentages which define the accuracy (highly accurate) of proposed model for the year 2003/2004 and year 2020.
3. As for the error analysis, errors greater than 3 percentage in the year 2020 is due to the irregularities in market like opening of the market in weekends and closing in business days, dealing a greater number of trades due to pandemic situation which is merely the case in the year 2003/2004.
4. The prediction of indices for 50 days gap in the year 2020 shows the trend of stock market if it was opened during that period of time resulting to latest published index at 11 May 2020 (actual NEPSE index 1226.16, predicted NEPSE index 1208.81 with error of 1.415%); the positive error representing presence of randomness in market.
5. Brownian motion model is found to be more accurate than other stochastic processes like random walk, Wiener process, Levy process etc. as it incorporates the diffusion and drift along with the properties of Wiener process incorporating both the deterministic parameter from historic data and the randomness by generating diffusion σB_k.

Acknowledgements

I would like to acknowledge NEPSE database center for conveying data needed. Moreover, I would like to thank Central Department of Physics (CDP) for all the support.

References

[1]. W.J. O'Neil, How to make Money in Stocks, 4th ed., The McGraw-Hill Companies, New York, 2009.
[2]. D. Owen and R. Griffiths, Mapping the Markets: A guide to Stock market Analysis, The Economist, London, 2006.
[3]. G. Sãvoiu, Econophysics: Background and Applications in Economics, Finance, and Sociophysics, Academic Press, Waltham, 2012.
[4]. C. Blomberg, 1st ed., Physics of Life: The Physicist's Road to Biology, Elsevier, Netherlands, 2007.

[5]. I. Karatzas and S. E. Shreve, 1st ed., Brownian motion and Stochastic Calculus, Springer, New York, 1987.

[6]. K. F. Vajargah and M. Shoghi, Simulation of Stochastic differential equation of geometric Brownian motion by quasi-Monte Carlo method and its application in prediction of total index of stock market and value at risk, Math Sci. 9 (2015) 115-125 https://doi.org/10.1007/s40096-015-0158-5

[7]. G. Dhesi et al., Modified Brownian motion Approach to Modeling Returns Distribution, Wilmott. 82 (2016) 74-77. https://doi.org/10.1002/wilm.10494

[8]. S. N. Z. Abidin and M. M. Jaffar, A Review on Geometric Brownian Motion in Forecasting the Share Prices in Bursa Malaysia, World Applied Sciences Journal. 17 (2012) 87-93. https://www.researchgate.net/publication/325986792

[9]. V. Singal, Beyond the random walk: A guide to stock market anomalies, Oxford University Press, USA, 2003.