The Analysis of Ansatzes for Optical Fibers Models

Zehra PINAR (✉ zpinar@nku.edu.tr)

Namik Kemal Universitesi <https://orcid.org/0000-0002-9344-7308>

Research Article

Keywords: Kundu-Mikherjee-Naskar model, the Schrödinger equation with anti-cubic nonlinearity, Optical solutions

Posted Date: April 27th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-425870/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

The Analysis of Ansatzes for Optical Fibers Models

Zehra Pinar

*Department of Mathematics, Faculty of Arts and Science, Tekirdağ Namık Kemal University, 59030 Tekirdağ,
Turkey*

zpinar@nku.edu.tr

Abstract

Optical fibers have a major role in the industry and daily life. To simulate the pulse propagation in optical fibers, numerous models are seen in the literature. In this work, the Kundu-Mikherjee-Naskar model and the Schrödinger equation with anti-cubic nonlinearity are considered. To solve these models, ansatz-based methods are considered and also, the problem about the determination of ansatz is replied so that it is not clear in the literature. The results of the proposed models will play a key role due to the applications in nonlinear optics, fluid dynamics, quantum mechanics and various other branches of science.

Kewwords: Kundu-Mikherjee-Naskar model; the Schrödinger equation with anti-cubic nonlinearity; Optical solutions.

1. Introduction

Solitons in optics are the basic structure of soliton transmission technology, data transmission, transoceanic and intercontinental distances, telecommunication, as well as molecules or pulses that form the base fabric as optical fibers in the world within seconds. [1]. Optical fibers have played an important role in the industry and in daily life, particularly in the telecommunications industry, for the last few decades, providing the latest technology in modern fiber optic communication technology. Soliton molecules have various aspects studied in various optoelectronic devices. One of the avenues of attention is the nonlinearity effects in a fiber such as ultrashort pulses, optical solitons, second harmonic generation, four-wave mixing, self-phase modulation, stimulated Raman scattering, etc. [2]. In the literature, many models such as Kaup-Newell equation [11], Lakshmanan-Porsezian-Daniel model [10], complex Ginzburg-Landau equation [14], Radhakrishnan-Kundu-Lakshmanan equation [15], Fokas-Lenells equation [12, 13] are seen to simulate the pulse propagation in optical fibers [1]. In 2014, Kundu et al. [3] proposed a new model for oceanic rogue waves as well as hole waves in deep sea. Additionally, the model can be applied to study optical wave propagation by means of consistent excited resonance waveguides contributed by soliton pulses, Erbium atoms [4, 5] and bending phenomena of light beams. With another view, the model is known as a new extension of the non-linear Schrödinger equation by incorporating non-linearities in different forms relative to the Kerr and non-Kerr law nonlinearities to investigate soliton pulses in $(2 + 1)$ - dimensions [1, 6]. Kundu-Mukherjee-Naskar (KMN) model [5] is given

$$iu_t + au_{xy} + ibu(uu_x^* - u^*u_x) = 0 \quad (1)$$

The two-dimensional soliton propagation dynamics and the temporal variable t along an optical fiber with the spatial variables are x and y , while the dependent variable $u(x, y, t)$ represents

the nonlinear wave envelope. The first term in (1) refers to temporal evolution of the wave followed by the dispersion term given by the coefficient of a . The coefficient of nonlinear term b is different from the conventional Kerr law nonlinearity or from any known non-Kerr law media. In (1), this nonlinear term accounts for “current-like” nonlinearity resulting from chirality.

It is known that Schrödinger equation is the main equation generally used to model phenomenon especially in quantum mechanics, energy and energy quantization. The linear Schrödinger equation defines the time evolution of a quantum state. The nonlinear Schrödinger equation is known as one of the universal equations that describe the evolution of slowly changing quasi-monochromatic wave packets in weakly nonlinear media that have dispersion [7]. Anti-Cubic nonlinearity differs from nonlinearity with respect to Kerr and non-Kerr law nonlinearities and is common to the dynamics of propagation of fibers through optical fibers for polarization preserving fibers.

The nonlinear Schrödinger's equation (NLSE) with anti-cubic nonlinearity is proposed

$$u_t + iau_{xx} + u(\sigma_1 |u|^{-4} + \sigma_2 |u|^2 + \sigma_3 |u|^4) = 0 \quad (2)$$

where the coefficient of group velocity dispersion is a . The nonlinearities stem out from the coefficients of $\sigma_i (i=1,2,3)$. In particular, σ_1 gives the effect of anti-cubic nonlinearity. In case $\sigma_1 = 0$, it is parabolic law nonlinearity that kicks in [8, 19].

The unclear problem about the ansatz is tried to reply so in the literature various determinations of ansatz are seen: Kudryashov [9] considers the ansatz as $u(x,t) = y(z)\exp(i\phi(z) - \omega t)$, $z = x - C_0 t$ whereas Zayed [8] proposed $u(x,t) = y(\xi)\exp(i\phi(x,t))$, $\xi = \mu(x - vt)$, $\phi(x,t) = -\kappa x + \omega t + \theta(\xi)$ to reduce Eq. (2) to the solvable system. In addition to them, most seen ansatzes are $u(x,t) = y(\xi)\exp(i\phi(\xi))$, $\xi = \mu(x - vt)$ and $u(x,t) = y(\xi)\exp(i\xi)$, $\xi = \mu(x - vt)$.

In this work, the most important models of optical fibers are solved via Bernoulli approximation method [16, 17, 18, 19] after reduction with the mentioned ansatz and the obtained solutions are compared.

2. Reductions and Results of the models:

In this section, for the considered two models of the optical fibers, analytical solutions are obtained via different ansatz proposed in the literature.

2.1. The nonlinear Schrödinger's equation (NLSE) with anti-cubic nonlinearity

Case 1. $u(x,t) = y(\xi)\exp(i\phi(x,t))$, $\xi = (x - mt)$, $\phi(x,t) = -\kappa x + \omega t + \theta(\xi)$ is considered to reduce the Eq. (2) into the system

$$\begin{aligned} y'(\xi)(-m - 2a\kappa + 2a\theta'(\xi)) + ay(\xi)\theta''(\xi) &= 0 \\ y^5(\xi)(-\omega - a\kappa^2 + (m + 2a\kappa)\theta'(\xi) - a(\theta'(\xi))^2) + ay^4(\xi)y''(\xi) + by(\xi) + cy^7(\xi) + \sigma y^9(\xi) &= 0 \end{aligned} \quad (3)$$

In the first equation of the system, assuming $-m - 2a\kappa + 2a\theta'(\xi) = 0$, therefore

$$\theta(\xi) = \left(\frac{m}{2a} + \kappa\right)\xi + C_1 \quad (4)$$

Substituting Eq. (4) into the second equation of Eq. (3), the nonlinear ordinary differential equation is obtained for $y(\xi)$

$$y^5(\xi) \left(-\omega - a\kappa^2 + (m + 2a\kappa) \left(\frac{m}{2a} + \kappa \right) - a \left(\frac{m}{2a} + \kappa \right)^2 \right) + ay^4(\xi)y''(\xi) + by(\xi) + cy^7(\xi) + \sigma y^9(\xi) = 0 \quad (5)$$

With the balancing principle, the solution is assumed as a finite series

$$y(\xi) = g_0 + g_1 z(\xi) \quad (6)$$

where g_0 and g_1 are parameters, $z(\xi)$ is the solution of the variable coefficient Bernoulli type differential equation

$$z'(\xi) = P(\xi)z(\xi) + Q(\xi)z^k(\xi), k \neq 0, 1 \quad (7)$$

Substituting the finite series (Eq. (6)) and Eq. (7) into Eq. (5), equating each coefficients of the power of $z(\xi)$, the algebraic system is obtained to determine the parameters.

In case $k = 2$, $P(\xi) = \pm \frac{g_0 \sqrt{2} (-20\sigma g_0^2 + c)}{\sqrt{-a(36\sigma g_0^2 + c)}}$, $Q(\xi) = \mp \frac{g_1 \sqrt{-2a(36\sigma g_0^2 + c)}}{2a}$ and $g_0 = \mp \frac{\sqrt{-ca(-4\omega a + m^2 + 4ma\kappa)}}{2ac}$, $g_1 = \frac{18C_2 g_0}{7 \exp\left(\mp \frac{g_0 \xi \sqrt{2}}{a \sqrt{-(1/ca)}}\right)}$, $\sigma = 0, b = 0$ are hold from the

algebraic system. Therefore, the solution of Eq(7) with the obtained parameters is

$$z(\xi) = \frac{2g_0(-20\sigma g_0^2 + c)}{-36g_1 g_0^2 \sigma - g_1 c - 40C_2 \sigma g_0^3 \exp\left(\frac{g_0 2(-20\sigma g_0^2 + c)}{\sqrt{-2a(36\sigma g_0^2 + c)}} \xi\right) + 2C_2 c g_0 \exp\left(\frac{g_0 2(-20\sigma g_0^2 + c)}{\sqrt{-2a(36\sigma g_0^2 + c)}} \xi\right)}$$

Substitute all results in Eq. (6) to obtain $y(\xi)$. Hence with known functions, $u(x, t)$ is hold and its figure is plotted in Figure 1(a) with $a = 1, c = -1, \omega = 1, C_1 = 1, C_2 = 1, \kappa = 0.4, m = 0.6$.

(a)

(b)

(c)

Figure 1. The solutions of Eq. (2) with different ansatzes considered each case, respectively.

Case 2. $u(x,t) = y(\xi)\exp(i\varphi(x,t) - \omega t)$, $\xi = (x - mt)$ is considered to reduce the Eq. (2) into the system

$$\begin{aligned} y'(\xi)(-m + 2a\varphi'(\xi)) + y(\xi)(a\varphi''(\xi) - \omega) &= 0 \\ y^5(\xi)(m\varphi'(\xi) - a(\varphi'(\xi))^2) + ay^4(\xi)y''(\xi) & \\ + by(\xi)\exp(4\omega t) + cy^7(\xi)\exp(-2\omega t) + \sigma y^9(\xi)\exp(-4\omega t) &= 0 \end{aligned} \quad (8)$$

In the first equation of the system, assuming $a\varphi''(\xi) - \omega = 0$, therefore $\varphi(\xi) = \frac{\omega}{2a}\xi^2 + C_1\xi + C_2$ and substituting the first equation of Eq. (8),

$$\varphi(\xi) = \frac{-\omega\xi^2 + m\xi + 2C_2a}{2a} \quad (9)$$

Substituting Eq. (9) into the second equation of Eq. (8), the nonlinear ordinary differential equation is obtained for $y(\xi)$

$$\begin{aligned} m^2 y^4(\xi) + 4a^2 y^3(\xi)y''(\xi) - 4\omega^2 y^4(\xi)\xi^2 + 4ba\exp(4\omega t) & \\ + 4acy^6(\xi)\exp(-2\omega t) + 4\sigma ay^8(\xi)\exp(-4\omega t) &= 0 \end{aligned} \quad (10)$$

The parameters are obtained as a result of the considered procedure for $k = 2$ in Eq. (7);

$$P(\xi) = \pm \frac{g_0 \sqrt{2} (3c \exp(-2\omega t) + 28\sigma g_0^2 \exp(-4\omega t))}{3\sqrt{-a \exp(-2\omega t) (28\sigma g_0^2 \exp(-2\omega t) + c)}}, Q(\xi) = \mp \frac{g_1 \sqrt{-2a \exp(-2\omega t) (28\sigma g_0^2 \exp(-2\omega t) + c)}}{2a}$$

and

$$g_0 = \mp \frac{\sqrt{-ac \exp(-2\omega t) (-4\omega^2 \xi^2 + m^2)}}{2ac \exp(-2\omega t)}, g_1 = \frac{4C_1 \sqrt{-ac \exp(-2\omega t) (-4\omega^2 \xi^2 + m^2)}}{ac \exp(-2\omega t) \exp\left(\frac{\xi \sqrt{2a^2 c^2 \exp(-4\omega t) (-4\omega^2 \xi^2 + m^2)}}{2a^2 c \exp(-2\omega t)}\right)}, \sigma = 0, b = 0$$

are hold from the algebraic system. Therefore, the solution of Eq.(7) with the obtained parameters is

$$z(\xi) = \frac{2g_0(-3c + 28\sigma g_0^2 \exp(-2\omega t)) \exp(-2\omega t)}{\left(\begin{aligned} & (84g_1g_0^2\sigma \exp(-2\omega t) + 3g_1c) \exp(-2\omega t) - 56C_1\sigma g_0^3 \exp(-4\omega t) \exp\left(-\frac{2g_0(-3c + 28\sigma g_0^2 \exp(-2\omega t))}{3\sqrt{-2a \exp(-4\omega t)(28\sigma g_0^2 + c \exp(2\omega t))}} \xi \right) \\ & - 6C_1c g_0 \exp\left(-\frac{2g_0(-3c + 28\sigma g_0^2 \exp(-2\omega t))}{3\sqrt{-2a \exp(-4\omega t)(28\sigma g_0^2 + c \exp(2\omega t))}} \xi - 2\omega t \right) \end{aligned} \right)}$$

Substitute all results in Eq. (6) to obtain $y(\xi)$. Hence with known functions, $u(x,t)$ is hold and its figure is plotted in Figure 1(b) with $a=1, c=-1, \omega=1, C_1=1, C_2=1, \kappa=0.4, m=0.6$.

Case 3. $u(x,t) = y(\xi) \exp(i\phi(x,t))$, $\xi = (x - mt)$ is considered to reduce the Eq(2) into the system

$$\begin{aligned} y'(\xi)(m - 2a\phi'(\xi)) - ay(\xi)\phi''(\xi) &= 0 \\ y^5(\xi)(-m\phi'(\xi) + a(\phi'(\xi))^2) - ay^4(\xi)y''(\xi) - by(\xi) - cy^7(\xi) - \sigma y^9(\xi) &= 0 \end{aligned} \quad (11)$$

In the first equation of the system, assuming $m - 2a\phi'(\xi) = 0$, therefore

$$\phi(\xi) = \frac{m}{2a}\xi + C_1 \quad (12)$$

Substituting Eq(12) into the second equation of Eq(11), the nonlinear ordinary differential equation is obtained for $y(\xi)$

$$m^2 y^4(\xi) + 4a^2 y^3(\xi) y''(\xi) + 4ba + 4cay^6(\xi) + 4a\sigma y^8(\xi) = 0 \quad (13)$$

With the same view for $k=2$, $P(\xi) = \pm \frac{g_0\sqrt{2}(3c - 28\sigma g_0^2)}{\sqrt{-a(28\sigma g_0^2 + c)}}$, $Q(\xi) = \mp \frac{g_1\sqrt{-2a(28\sigma g_0^2 + c)}}{2a}$

and $g_0 = \mp \frac{m}{2} \sqrt{-\frac{1}{ca}}$, $g_1 = \frac{8C_2g_0}{3 \exp\left(\mp \frac{g_0\xi\sqrt{2}}{a\sqrt{-(1/ca)}}\right)}$, $\sigma=0, b=0$ are hold from the algebraic

system. Therefore, the solution of Eq. (7) with the obtained parameters is

$$z(\xi) = \frac{2g_0(3c - 28\sigma g_0^2)}{-84g_1g_0^2\sigma - 3g_1c - 56C_2\sigma g_0^3 \exp\left(\frac{2g_0(3c - 28\sigma g_0^2)}{3\sqrt{-2a(28\sigma g_0^2 + c)}} \xi\right) + 6C_2c g_0 \exp\left(\frac{g_0 2(3c - 28\sigma g_0^2)}{\sqrt{-2a(28\sigma g_0^2 + c)}} \xi\right)}$$

Substitute all results in Eq. (6) to obtain $y(\xi)$. Hence with known functions, $u(x,t)$ is hold and its figure is plotted in Figure 1(c) with $a=1, c=-1, \omega=1, C_1=1, C_2=1, \kappa=0.4, m=0.6$.

When $\kappa=0$ in Case 1, it reduces into the considered ansatz in Case 2. In addition to this reduction, in Case 1 $\kappa=0, \omega=0$ and in Case 2 $\omega=0$, both cases are reduced into the

considered ansatz in Case 3. The comparisons of cases are given with the plots of solution in Figure 2.

Case 1 for $\kappa = 0$

Case 2

Case 1 for $\kappa = 0, \omega = 0$

Case 2 $\omega = 0$

Figure 2. The comparison of the considered ansatz.

As it is seen from Figure 2, the ansatz is reduced to each other and have similar behavior. In the following, it is proved that when the ansatz is chosen as $u(x,t) = y(\xi) \exp(i\varphi(x,t))$, $\xi = (x - mt)$, the behavior depends on the parameter m that is the wave speed.

$m = 0.1$

$m = 0.6$

$m = 0.9$

$m = 1.3$

Figure 3. The changes of the solutions due to different values of the parameter m when the ansatz is chosen as $u(x,t) = y(\xi)\exp(i\varphi(x,t))$, $\xi = (x - mt)$.

2.2. Kundu–Mukherjee–Naskar (KMN) model

Case 1. $u(x,t) = y(\xi)\exp(i\varphi(x,t))$, $\xi = (x + y - mt)$, $\varphi(x,t) = -\kappa x + \omega t + \theta(\xi)$ is considered to reduce the Eq. (1) into the system

$$\begin{aligned} y'(\xi) \left(-m + A(\kappa - l) + 2A\theta'(\xi) \right) + Ay(\xi)\theta''(\xi) &= 0 \\ y(\xi) \left(-\omega - A\kappa + (m + A(\kappa + l))\theta'(\xi) - A(\theta'(\xi))^2 \right) + Ay''(\xi) - 2By^3(\xi)(\kappa - \theta'(\xi)) &= 0 \end{aligned} \quad (14)$$

In the first equation of the system, assuming $-m + A(\kappa - l) + 2A\theta'(\xi)$, therefore

$$\theta(\xi) = -\left(\frac{-m - A(l - \kappa)}{2A}\right)\xi + C_1 \quad (15)$$

Substituting Eq. (15) into the second equation of Eq. (14), the nonlinear ordinary differential equation is obtained for $y(\xi)$

$$y(\xi) \left(-\omega - A\kappa l - \frac{m(-m - A(l - \kappa))}{2A} - \frac{(l + \kappa)(-m - A(l - \kappa))}{2} - \frac{(-m - A(l - \kappa))^2}{4A} \right) + Ay''(\xi) + \left(-2\kappa - \frac{(-m - A(l - \kappa))}{A} \right) By^3(\xi) = 0 \quad (16)$$

Applying the procedure $k = 2$ for Eq. (7),

$$P(\xi) = \pm \frac{Bg_0\sqrt{2}(A(3\kappa - l) - m)}{A\sqrt{B(A(3\kappa - l) - m)}}, Q(\xi) = \mp \frac{g_1\sqrt{2B(A(3\kappa - l) - m)}}{2A} \text{ and } g_0 = \mp \frac{\sqrt{-B(A(3\kappa - l) - m)(4A\omega - 2mA\kappa - A^2l^2 + 2A^2l\kappa - m^2 + 3A^2\kappa^2 - 2Alm)}}{2B(A(3\kappa - l) - m)} \text{ are hold from}$$

the algebraic system. Therefore, the solution of Eq. (7) with the obtained parameters is

$$z(\xi) = \frac{2g_0}{g_1 + 2C_2g_0 \exp\left(\frac{Bg_0\sqrt{2}(A(3\kappa - l) - m)}{A\sqrt{B(A(3\kappa - l) - m)}}\xi\right)}$$

Substitute all results in Eq. (6) to obtain $y(\xi)$. Hence with known functions, $u(x, y, t)$ is hold and its figure is plotted in Figure 4(a) with $A = -1, B = 1, \omega = 1, l = 1, C_1 = 1, C_2 = 1, \kappa = 0.4, m = 0.6, g_1 = 2, y = 1$.

Figure 4. The solutions of Eq. (1) for Case1 and Case 3, respectively.

Case 2. $u(x,t) = y(\xi) \exp(i\phi(\xi) - \omega t)$, $\xi = (x + y - mt)$ is considered to reduce the Eq. (2) into the system

$$\begin{aligned} y'(\xi)(m - 2A\phi'(\xi)) - y(\xi)(A\phi''(\xi) - \omega) &= 0 \\ y(\xi)\phi'(\xi)(m - A\phi'(\xi) + 2By^2(\xi)\exp(-2\omega t)) + Ay''(\xi) &= 0 \end{aligned} \quad (17)$$

In the first equation of the system, assuming $A\phi''(\xi) - \omega = 0$, therefore

$$\phi(\xi) = \frac{-\omega\xi^2 - m\xi + 2C_2A}{2A} \quad (18)$$

Substituting Eq. (18) into the second equation of Eq(17), the nonlinear ordinary differential equation is obtained for $y(\xi)$

$$Ay''(\xi) + \frac{(-4mB - 8\omega B\xi)e^{-2\omega t}y^3(\xi)}{4A} + \frac{(-3m^2 - 4\omega^2\xi^2 - 8m\omega\xi)}{4A}y(\xi) = 0 \quad (19)$$

Applying the procedure $k = 2$ for Eq. (7),

$$P(\xi) = \pm \frac{\sqrt{2}(-6(m + 2\omega\xi)g_0\sqrt{(m + 2\omega\xi)Be^{-2\omega t}} + A\omega\sqrt{2})}{6A(m + 2\omega\xi)}, Q(\xi) = \mp \frac{g_1\sqrt{2(m + 2\omega\xi)Be^{-2\omega t}}}{2A}$$

and $g_0 = \mp \frac{\sqrt{-Be^{-2\omega t}(3m + 2\omega\xi)}}{2Be^{-2\omega t}}$, $A = -\frac{3(m + 2\omega\xi)Be^{-2\omega t}\sqrt{-2(m + 2\omega\xi)(3m + 2\omega\xi)}}{14B\omega e^{-2\omega t}}$ are hold

from the algebraic system. Substitute all results in Eq. (6) to obtain $y(\xi)$. Hence with known functions, $u(x, y, t)$ is hold.

Case 2. $u(x,t) = y(\xi) \exp(i\phi(x,t))$, $\xi = (x + y - mt)$ is considered to reduce the Eq. (2) into the system

$$\begin{aligned} y'(\xi)(-m - 2A\phi'(\xi)) - Ay(\xi)\phi''(\xi) &= 0 \\ y(\xi)(-m\phi'(\xi) + A(\phi'(\xi))^2) - Ay''(\xi) - 2By^3(\xi)\phi'(\xi) &= 0 \end{aligned} \quad (20)$$

In the first equation of the system, assuming $m + 2A\phi'(\xi) = 0$, therefore

$$\phi(\xi) = -\frac{m}{2A}\xi + C_1 \quad (21)$$

Substituting Eq. (21) into the second equation of Eq. (20), the nonlinear ordinary differential equation is obtained for $y(\xi)$

$$\frac{3m^2y(\xi)}{4A} - Ay''(\xi) + \frac{B}{A}my^3(\xi) = 0 \quad (22)$$

Applying the procedure $k = 2$ for Eq. (7), $P(\xi) = \pm \frac{g_0mB\sqrt{2}}{A\sqrt{Bm}}$, $Q(\xi) = \mp \frac{g_1\sqrt{2Bm}}{2A}$ and

$g_0 = \mp \frac{\sqrt{-3Bm}}{2B}$ are hold from the algebraic system. Therefore, the solution of Eq. (7) with the

obtained parameters is

$$z(\xi) = \frac{2}{Bmg_1 - 2C_2 \exp\left(\frac{\sqrt{2}}{A\sqrt{Bm}} \xi\right)}$$

Substitute all results in Eq. (6) to obtain $y(\xi)$. Hence with known functions, $u(x, y, t)$ is hold and its figure is plotted in Figure 4(b) with $A = -1, B = 1, \omega = 1, C_1 = 1, C_2 = 1, \kappa = 0.4, m = 0.6, g_1 = 2$.

Case 1 for $\kappa = 0, \omega = 0$

Case 2 $\omega = 0$

Case 3

Figure 5. The comparison of the considered ansatz.

Conclusion

In this work, the Kundu-Mikherjee-Naskar model and the Schrödinger equation with anti-cubic nonlinearity are considered and solved via Bernoulli approximation method with different type of ansatzes. $u(x, t) = y(\xi) \exp(i\phi(\xi)), \xi = (x - mt)$ is the main ansatz although the others generate new

solutions. So, it is seen from the Figure 3, for various values of the parameter m , the given solutions via the other ansatzes are obtained. Therefore, the unclear problem about the ansatz is solved.

References

- [1] Y. Yıldırım, Optical solitons to Kundu–Mukherjee–Naskar model in birefringent fibers with trial equation approach, *Optik - International Journal for Light and Electron Optics* 183 (2019) 1026–1031
- [2] A. Biswas, M. Ekici, A. Sonmezoglu, M. R. Belic, Optical solitons in birefringent fibers having anti-cubic nonlinearity with extended trial function, *Optik - International Journal for Light and Electron Optics* 185 (2019) 456–463
- [3] A. Kundu, A. Mukherjee, T. Naskar, Modelling rogue waves through exact dynamical lump soliton controlled by ocean currents, *Proc. R. Soc. A* 470 (2014) 20130576.
- [4] A. Biswas, Y. Yıldırım, E. Yasar, Q. Zhou, S.P. Moshokoa, M. Belic, Optical soliton perturbation with quadratic–cubic nonlinearity using a couple of strategic algorithms, *Chin. J. Phys.* 56 (2018) 1990–1998.
- [5] M. Ekici, A. Sonmezoglu, A. Biswas, M. R. Belic, Optical solitons in (2+1)–Dimensions with Kundu–Mukherjee–Naskar equation by extended trial function scheme, *Chinese Journal of Physics* 57 (2019) 72–77
- [6] A. Biswas, Y. Yıldırım, E. Yasar, Q. Zhou, A.S. Alshomrani, S.P. Moshokoa, M. Belic, Dispersive optical solitons with Schrödinger–Hirota model by trial equation method, *Optik* 162 (2018) 35–41.
- [7] B. Malomed, (2005). Nonlinear Schrödinger Equations, in Scott, A. (ed.), *Encyclopedia of Nonlinear Science*, New York, Routledge, 639–643.
- [8] E. M.E. Zayed, M. E.M. Alngar, A.-G. Al-Nowehy, On solving the nonlinear Schrödinger equation with an anti-cubic nonlinearity in presence of Hamiltonian perturbation terms, *Optik - International Journal for Light and Electron Optics* 178 (2019) 488–508
- [9] N.A. Kudryashov, First integrals and general solution of the traveling wave reduction for Schrödinger equation with anti-cubic nonlinearity, *Optik - International Journal for Light and Electron Optics* 185 (2019) 665–671
- [10] A. Biswas, Y. Yıldırım, E. Yaşar, R.T. Alqahtani, Optical solitons for Lakshmanan–Porsezian–Daniel model with dual-dispersion by trial equation method, *Optik* 168 (2018) 432–439.
- [11] A. Biswas, Y. Yıldırım, E. Yaşar, Q. Zhou, S.P. Moshokoa, M. Belic, Sub pico-second pulses in mono-mode optical fibers with Kaup–Newell equation by a couple of integration schemes, *Optik* 167 (2018) 121–128.
- [12] A. Biswas, Y. Yıldırım, E. Yasar, Q. Zhou, M.F. Mahmood, S.P. Moshokoa, M. Belic, Optical solitons with differential group delay for coupled Fokas–Lenells equation using two integration schemes, *Optik* 165 (2018) 74–86.
- [13] A. Biswas, Y. Yıldırım, E. Yaşar, Q. Zhou, S.P. Moshokoa, M. Belic, Optical soliton solutions to Fokas–Lenells equation using some different methods, *Optik* 173 (2018) 21–31.
- [14] A. Biswas, Y. Yıldırım, E. Yasar, H. Triki, A.S. Alshomrani, M.Z. Ullah, Q. Zhou, S.P. Moshokoa, M. Belic, Optical soliton perturbation with complex Ginzburg–Landau equation using trial solution approach, *Optik* 160 (2018) 44–60.
- [15] A. Biswas, Y. Yıldırım, E. Yasar, M.F. Mahmood, A.S. Alshomrani, Q. Zhou, S.P. Moshokoa, M. Belic, Optical soliton perturbation for Radhakrishnan–Kundu–Lakshmanan equation with a couple of integration schemes, *Optik* 163 (2018) 126–136.

- [16] H. Kocak, Z. Pinar, On solutions of the fifth-order dispersive equations with porous medium type non-linearity, *Waves in Random and Complex Media* 28(3), 516-522(2018).
- [17] Z. Pinar, H. Kocak, Exact solutions for the third-order dispersive-Fisher equations, *Nonlinear Dyn* 91, 421–426 (2018).
- [18] Z. Pinar, T. Ozis, A remark on a variable-coefficient Bernoulli equation based on auxiliary-equation method for nonlinear physical systems- *arXiv preprint arXiv:1511.02154*, 2015
- [19] Z. Pinar, H. Rezazadeh, M. Eslami, Generalized logistic equation method for Kerr law and dual power law Schrödinger equations, *Optical and Quantum Electronics* 52 (12), 1-16 (2020)

Figures

(a)

(b)

(c)

Figure 1

The solutions of Eq. (2) with different ansatzes considered each case, respectively.

Case 1 for $\kappa=0$

Case 2

Case 1 for $\kappa=0, \omega=0$

Case 2 $\omega=0$

Figure 2

The comparison of the considered ansatz.

$m = 0.1$

$m = 0.6$

$m = 0.9$

$m = 1.3$

Figure 3

Please see the Manuscript PDF file for the complete figure caption

(a)

(b)

Figure 4

The solutions of Eq. (1) for Case1 and Case 3, respectively.

Case 1 for $\kappa=0, \omega=0$

Case 2 $\omega=0$

Case 3

Figure 5

The comparison of the considered ansatz