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Research Article

The (G'/G)-Expansion Method for Abundant Traveling Wave Solutions of Caudrey-Dodd-Gibbon Equation

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We construct the traveling wave solutions of the fifth-order Caudrey-Dodd-Gibbon (CDG) equation by the (G'/G)-expansion method. Abundant traveling wave solutions with arbitrary parameters are successfully obtained by this method and the wave solutions are expressed in terms of the hyperbolic, the trigonometric, and the rational functions. It is shown that the (G'/G)-expansion method is a powerful and concise mathematical tool for solving nonlinear partial differential equations.

1. Introduction

The investigation of exact traveling wave solutions of nonlinear partial differential equations (NLPDEs) plays an important role in the analysis of complex physical phenomena. The NLPDEs appear in physical sciences, various scientific and engineering problems, such as, fluid mechanics, plasma physics, optical fibers, biology, solid state physics, chemical kinematics, chemical physics, chemistry and many others. In recent years, to obtain exact traveling wave solutions of NLPDEs, many effective and powerful methods have been presented in the literature, such as the Backlund transformation [1], the tanh function method [2], the extended tanh function method [3], the variational iteration method [4], the Adomian decomposition method [5, 6], the homotopy perturbation method [7], the F-expansion method [8], the Hirota's bilinear method [9], the exp-function method [10], the Cole-Hopf transformation [11], the general projective Riccati equation method [12] and others [13–20], Nowaday, searching analytical solutions of the NLPDEs has become more lucrative partly due to the accessibility computer symbolic systems, like Maple, Mathematica, and Matlab, which help us to calculate the complicated and wearisome algebraic calculations on computer.

Recently, Wang et al. [21] introduced a new direct method called the (G'/G)-expansion method to seek traveling wave solutions of the nonlinear evolution equations. Abazari [22] implemented the (G'/G)-expansion method to NLEEs related to fluid mechanics. Zheng [23] used the method for getting exact traveling wave solutions of two different types of equations. Feng et al. [24] used the method to seek solutions of the Kolmogorov-Petrovskii-Piskunov equation. Liu et al. [25] concerned the method to simplified MCH equation and Gardner equation. Feng [26] applied the method to the seventh-order Sawada-Kotera equation.

At present time, Guo and Zhou [27] first proposed the extended (G'/G)-expansion method based on new ansatz. They applied the method to the Whitham-Broer-Kaup-Like equations and couple Hirota-Satsuma KdV equations. Zayed et al. [28] used extended (G'/G)-expansion method to some nonlinear PDEs in mathematical physics. Zhang et al. [29] presented an improved (G'/G)-expansion method for solving nonlinear evolution equations (NLEEs). Li et al. [30] introduced $(G'/G, 1/G)$-expansion method to obtain traveling wave solutions of the Zakharov equations. Hayek [31] proposed extended (G'/G)-expansion method for constructing exact solutions to the KdV Burgers equations with power-law nonlinearity.

In this paper, our aim is to investigate abundant new exact traveling wave solutions of the fifth-order Caudrey-Dodd-Gibbon equation by the (G'/G)-expansion method.

2. Description of the (G'/G)-Expansion Method

Suppose that the nonlinear partial differential equation is of the form

$$P(u, u_t, u_x, u_{tt}, u_{xt}, u_{xx}, \ldots) = 0, \tag{2.1}$$

where $u = u(x, t)$ is an unknown function and P is a polynomial in $u = u(x, t)$ which has various partial derivatives, and the highest order derivatives and nonlinear terms are involved.

The main steps of the (G'/G)-expansion method [21] are conveyed in the following.

Step 1. The traveling wave transformation:

$$u(x, t) = v(\xi), \qquad \xi = x + st, \tag{2.2}$$

where s is the wave speed, ξ is the combination of two independent variables x and t, transform (2.1) into an ordinary differential equation for $v(\xi)$:

$$Q\left(v, sv', v', s^2v'', sv'', v'', \ldots\right) = 0, \tag{2.3}$$

where primes denote the ordinary derivatives with respect to ξ.

Step 2. If possible, integrate (2.3) term by term for one or more times, yields constant(s) of integration. For simplicity, the integration constant(s) may be zero.

Step 3. Suppose that the solution of (2.3) can be expressed by a polynomial in (G'/G):

$$v(\xi) = \alpha_m \left(\frac{G'}{G}\right)^m + \alpha_{m-1}\left(\frac{G'}{G}\right)^{m-1} + \cdots + \alpha_0, \tag{2.4}$$

where α_n $(n = 0, 1, 2, 3, \ldots, m)$ are constants and $\alpha_m \neq 0$, and $G = G(\xi)$ satisfies the second order linear ordinary differential equation (LODE):

$$G'' + \lambda G' + \mu G = 0, \tag{2.5}$$

where λ and μ are arbitrary constants. The positive integer m can be determined by considering the homogeneous balance between the highest order derivatives and the nonlinear terms appearing in (2.3).

Step 4. Substituting (2.4) together with (2.5) into (2.3) yields an algebraic equation involving powers of (G'/G). Then, equating coefficients of each power of (G'/G) to zero yields a set of algebraic equations for α_n $(n = 0, 1, 2, 3, \ldots, m)$, s, λ, and μ. Since the general solution of (2.5) is known for us, then substituting α_n $(n = 0, 1, 2, 3, \ldots, m)$ and s together with general solution of (2.5) into (2.4), we obtain exact traveling wave solutions of the nonlinear partial differential equation (2.1).

3. Application of the Method

In this section, we apply the method to construct the hyperbolic, the trigonometric, and the rational function solutions of the fifth-order Caudrey-Dodd-Gibbon equation, and the solutions are shown in graphs.

3.1. The Caudrey-Dodd-Gibbon Equation

We consider the fifth-order Caudrey-Dodd-Gibbon equation:

$$u_t + u_{xxxxx} + 30uu_{xxx} + 30u_x u_{xx} + 180u^2 u_x = 0. \tag{3.1}$$

Now, we use the transformation equation (2.2) into (3.1), which yields,

$$sv' + v^{(5)} + 30vv''' + 30v'v'' + 180v^2 v' = 0, \tag{3.2}$$

where primes denote the derivative with respect to ξ.

Equation. (3.2) is integrable, therefore, integrating once with respect to ξ yields

$$sv + v^{(4)} + 30vv'' + 60v^3 + C = 0, \tag{3.3}$$

where C is an integral constant, that is, to be determined later.

Considering the homogeneous balance between $v^{(4)}$ and v^3 in (3.3), we obtain $m = 2$. Therefore, the solution of (3.3) is of the form:

$$v(\xi) = \alpha_2\left(\frac{G'}{G}\right)^2 + \alpha_1\left(\frac{G'}{G}\right) + \alpha_0, \tag{3.4}$$

where α_2, α_1, and α_0 are constants and $\alpha_2 \neq 0$. Substituting (3.4) together with (2.5) into (3.3) and collecting all terms with the same power of (G'/G) and setting each coefficient of the resulted polynomial to zero, we obtain a set of algebraic equations for α_2, α_1, α_0, s, λ, μ, and C as follows:

$$\begin{aligned}
&60\alpha_2^3 + 120\alpha_2 + 180\alpha_2^2 = 0,\\
&180\alpha_2^2\alpha_1 + 240\alpha_2\alpha_1 + 300\alpha_2^2\lambda + 336\alpha_2\lambda + 24\alpha_1 = 0,\\
&180\alpha_2\alpha_1^2 + 180\alpha_2^2\alpha_0 + 240\alpha_2^2\mu + 120\alpha_2^2\lambda^2 + 180\alpha_0\alpha_2 + 330\alpha_2\lambda^2\\
&\quad + 240\alpha_2\mu + 60\alpha_1\lambda + 60\alpha_1^2 + 390\alpha_2\alpha_1\lambda = 0,\\
&360\alpha_2\alpha_1\alpha_0 + 60\alpha_1^3 + 440\alpha_2\lambda\mu + 90\alpha_1^2\lambda + 60\alpha_0\alpha_1 + 40\alpha_1\mu + 130\alpha_2\lambda^3\\
&\quad + 50\alpha_1\lambda^2 + 180\alpha_2^2\lambda\mu + 300\alpha_2\alpha_1\mu + 150\alpha_2\alpha_1\lambda^2 + 300\alpha_0\alpha_2\lambda = 0,\\
&180\alpha_2\alpha_0^2 + 180\alpha_1^2\alpha_0 + 210\alpha_2\alpha_1\lambda\mu + 60\alpha_2^2\mu^2 + 60\alpha_1^2\mu + 30\alpha_1^2\lambda^2 + s\alpha_2 + 136\alpha_2\mu^2\\
&\quad + 16\alpha_2\lambda^4 + 15\alpha_1\lambda^3 + 60\alpha_1\lambda\mu + 232\alpha_2\lambda^2\mu + 240\alpha_0\alpha_2\mu + 90\alpha_0\alpha_1\lambda + 120\alpha_0\alpha_2\lambda^2 = 0,\\
&180\alpha_1\alpha_0^2 + 180\alpha_0\alpha_2\lambda\mu + 16\alpha_1\mu^2 + s\alpha_1 + \alpha_1\lambda^4 + 22\alpha_1\lambda^2\mu + 120\alpha_2\lambda\mu^2 + 30\alpha_2\lambda^3\mu\\
&\quad + 60\alpha_1\alpha_2\mu^2 + 30\alpha_1^2\lambda\mu + 60\alpha_0\alpha_1\mu + 30\alpha_0\alpha_1\lambda^2 = 0,\\
&60\alpha_0^3 + 14\alpha_2\lambda^2\mu^2 + \alpha_1\lambda^3\mu + 8\alpha_1\lambda\mu^2 + 16\alpha_2\mu^3 + C + 60\alpha_0\alpha_2\mu^2 + s\alpha_0 + 30\alpha_0\alpha_1\lambda\mu = 0.
\end{aligned} \tag{3.5}$$

Solving the system of algebraic equations with the aid of Maple 13, we obtain two different sets of solution.

Case 1. One has

$$\begin{gathered}
\alpha_0 = \frac{-1}{6}\lambda^2 - \frac{4}{3}\mu, \qquad \alpha_1 = -2\lambda, \qquad \alpha_2 = -2, \qquad s = -\lambda^4 + 8\mu\lambda^2 - 16\mu^2,\\
C = \frac{1}{9}\lambda^6 - \frac{4}{3}\lambda^4\mu + \frac{16}{3}\lambda^2\mu^2 - \frac{64}{9}\mu^3,
\end{gathered} \tag{3.6}$$

where λ and μ are arbitrary constants.

Case 2. One has

$$\begin{gathered}
\alpha_1 = -\lambda, \qquad \alpha_2 = -1, \qquad s = -180\alpha_0^2 - 30\lambda^2\alpha_0 - 22\mu\,\lambda^2 - 76\mu^2 - \lambda^4 - 240\mu\alpha_0,\\
C = 120\alpha_0^3 + 22\lambda^2\mu^2 + \lambda^4\mu + 16\mu^3 + 136\alpha_0\mu^2 + 30\lambda^2\alpha_0^2 + 52\alpha_0\lambda^2\mu + \alpha_0\lambda^4 + 240\mu\alpha_0^2,
\end{gathered} \tag{3.7}$$

where α_0, λ, and μ are arbitrary constants.

Case 1. Substituting (3.6) into (3.4) yields

$$v(\xi) = -2\left(\frac{G'}{G}\right)^2 - 2\lambda\left(\frac{G'}{G}\right) - \frac{1}{6}\lambda^2 - \frac{4}{3}\mu. \tag{3.8}$$

Substituting the general solution of (2.5) into (3.8), we obtain three types of traveling wave solutions of (3.3) as follows.

Hyperbolic Function Solutions

When $\lambda^2 - 4\mu > 0$, substituting the general solution of (2.5) into (3.8), we obtain the following traveling wave solution of (3.3):

$$v(\xi) = -\frac{\lambda^2 - 4\mu}{2}\left(\frac{C_1 \sinh(1/2)\sqrt{\lambda^2 - 4\mu}\xi + C_2 \cosh(1/2)\sqrt{\lambda^2 - 4\mu}\xi}{C_1 \cosh(1/2)\sqrt{\lambda^2 - 4\mu}\xi + C_2 \sinh(1/2)\sqrt{\lambda^2 - 4\mu}\xi}\right)^2 + \frac{1}{3}\lambda^2 - \frac{4}{3}\mu, \tag{3.9}$$

where $\xi = x + (-\lambda^4 + 8\mu\lambda^2 - 16\mu^2)t$, C_1, and C_2 are arbitrary constants. The various known results can be rediscovered, if C_1 and C_2 are taken as special values. For example:

(i) if $C_1 = 0$ but $C_2 \neq 0$, we obtain

$$v(\xi) = -\frac{\lambda^2 - 4\mu}{2}\coth^2\frac{1}{2}\sqrt{\lambda^2 - 4\mu}\xi + \frac{1}{3}\lambda^2 - \frac{4}{3}\mu. \tag{3.10}$$

(ii) If $C_2 = 0$ but $C_1 \neq 0$, we obtain

$$v(\xi) = -\frac{\lambda^2 - 4\mu}{2}\tanh^2\frac{1}{2}\sqrt{\lambda^2 - 4\mu}\xi + \frac{1}{3}\lambda^2 - \frac{4}{3}\mu. \tag{3.11}$$

(iii) If $C_1 \neq 0$ and $C_1^2 > C_2^2$, we obtain

$$v(\xi) = \frac{\lambda^2 - 4\mu}{2}\operatorname{sech}^2\left(\frac{1}{2}\sqrt{\lambda^2 - 4\mu}\xi + \xi_0\right) - \frac{\lambda^2}{6} + \frac{2}{3}\mu, \tag{3.12}$$

where $\xi_0 = \tanh^{-1}(C_2/C_1)$.

Trigonometric Function Solutions

When $\lambda^2 - 4\mu < 0$, we obtain

$$v(\xi) = -\frac{4\mu - \lambda^2}{2}\left(\frac{-C_1 \sin(1/2)\sqrt{4\mu - \lambda^2}\xi + C_2 \cos(1/2)\sqrt{4\mu - \lambda^2}\xi}{C_1 \cos(1/2)\sqrt{4\mu - \lambda^2}\xi + C_2 \sin(1/2)\sqrt{4\mu - \lambda^2}\xi}\right)^2 + \frac{1}{3}\lambda^2 - \frac{4}{3}\mu, \tag{3.13}$$

where $\xi = x + (-\lambda^4 + 8\mu\lambda^2 - 16\mu^2)t$, C_1 and C_2 are arbitrary constants.

The various known results can be rediscovered, if C_1 and C_2 are taken as special values.

Rational Function Solution

When $\lambda^2 - 4\mu = 0$, we obtain

$$v(\xi) = -\frac{2C_2^2}{(C_1 + C_2\xi)^2} + \frac{1}{3}\lambda^2 - \frac{4}{3}\mu, \tag{3.14}$$

where $\xi = x + (-\lambda^4 + 8\mu\lambda^2 - 16\mu^2)t$, C_1, and C_2 are arbitrary constants.

Case 2. Substituting (3.7) into (3.4) yields

$$v(\xi) = -\left(\frac{G'}{G}\right)^2 - \lambda\left(\frac{G'}{G}\right) + \alpha_0. \tag{3.15}$$

Substituting the general solution of (2.5) into (3.15), we obtain three types of traveling wave solutions of (3.3) as follows.

Hyperbolic Function Solutions

When $\lambda^2 - 4\mu > 0$, we obtain

$$v(\xi) = -\frac{\lambda^2 - 4\mu}{2}\left(\frac{C_1 \sinh(1/2)\sqrt{\lambda^2 - 4\mu}\xi + C_2 \cosh(1/2)\sqrt{\lambda^2 - 4\mu}\xi}{C_1 \cosh(1/2)\sqrt{\lambda^2 - 4\mu}\xi + C_2 \sinh(1/2)\sqrt{\lambda^2 - 4\mu}\xi}\right)^2 + \frac{1}{4}\lambda^2 + \alpha_0, \tag{3.16}$$

where $\xi = x + (-180\alpha_0^2 - 30\lambda^2\alpha_0 - 22\mu\lambda^2 - 76\mu^2 - \lambda^4 - 240\mu\alpha_0)t$. C_1 and C_2 are arbitrary constants.

The various known results can be rediscovered, if C_1 and C_2 are taken as special values.

Trigonometric Function Solutions

When $\lambda^2 - 4\mu < 0$, we obtain

$$v(\xi) = -\frac{4\mu - \lambda^2}{4}\left(\frac{-C_1 \sin(1/2)\sqrt{4\mu - \lambda^2}\xi + C_2 \cos(1/2)\sqrt{4\mu - \lambda^2}\xi}{C_1 \cos(1/2)\sqrt{4\mu - \lambda^2}\xi + C_2 \sin(1/2)\sqrt{4\mu - \lambda^2}\xi}\right)^2 + \frac{1}{4}\lambda^2 + \alpha_0, \tag{3.17}$$

where $\xi = x + (-180\alpha_0^2 - 30\lambda^2\alpha_0 - 22\mu\lambda^2 - 76\mu^2 - \lambda^4 - 240\mu\alpha_0)t$. C_1 and C_2 are arbitrary constants. The various known results can be rediscovered, if C_1 and C_2 are taken as special values. For example:

(i) if $C_1 = 0$ but $C_2 \neq 0$, we obtain

$$v(\xi) = -\frac{4\mu - \lambda^2}{4}\cot^2\frac{1}{2}\sqrt{4\mu - \lambda^2}\xi + \frac{1}{4}\lambda^2 + \alpha_0. \tag{3.18}$$

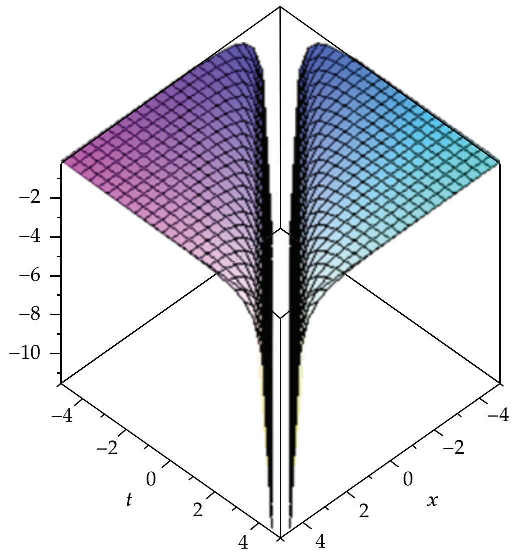

Figure 1: Solitary wave obtained from solution (3.10), for $\lambda = 3$, $\mu = 2$.

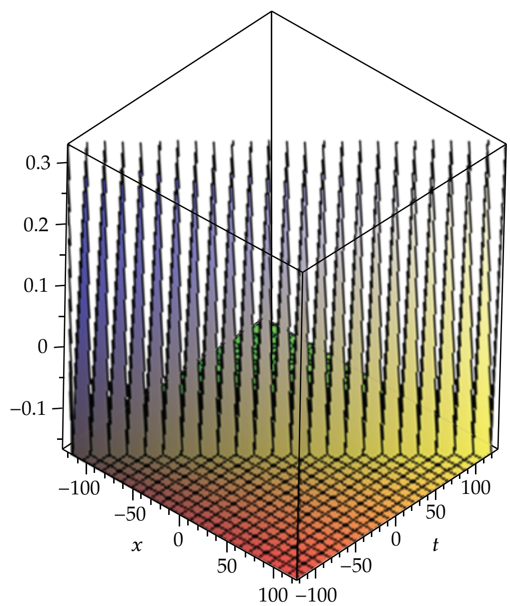

Figure 2: Solitary wave obtained from solution (3.11), for $\lambda = 3$, $\mu = 2$.

(ii) If $C_2 = 0$ but $C_1 \neq 0$, we obtain

$$v(\xi) = \frac{\lambda^2 - 4\mu}{4}\tan^2\frac{1}{2}\sqrt{4\mu - \lambda^2}\xi + \frac{1}{4}\lambda^2 + \alpha_0. \tag{3.19}$$

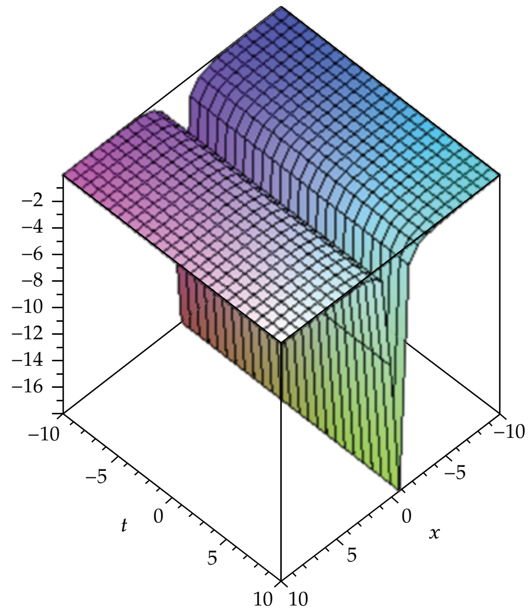

Figure 3: Solitary wave obtained from solution (3.14), for $\lambda = 2$, $\mu = 1$, $C_1 = 1$, $C_2 = 2$.

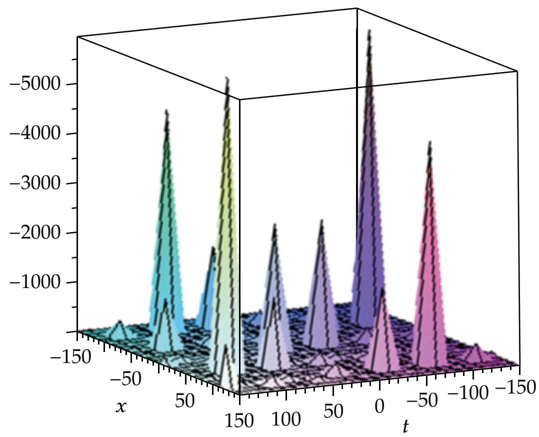

Figure 4: Solitary wave obtained from solution (3.19), for $\lambda = 1$, $\mu = 1$, $\alpha_0 = 1$.

(iii) If $C_1 \neq 0$ and $C_1^2 > C_2^2$, we obtain

$$v(\xi) = -\frac{4\mu - \lambda^2}{4}\cot^2\left(\frac{1}{2}\sqrt{4\mu - \lambda^2}\xi + \xi_0\right) + \frac{1}{4}\lambda^2 + \alpha_0, \tag{3.20}$$

where $\xi_0 = \tan^{-1} C_2/C_1$.

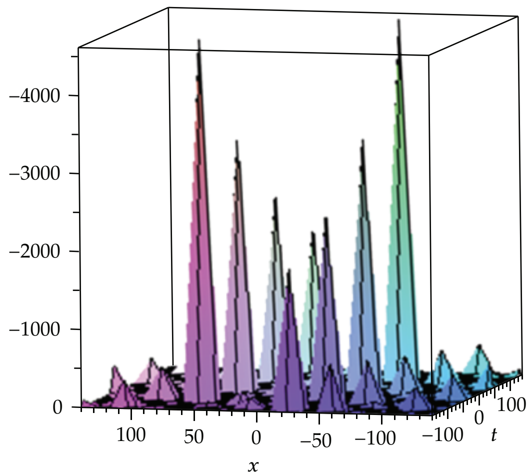

Figure 5: Solitary wave obtained from solution (3.19), for $\lambda = 1$, $\mu = 1$, $\alpha_0 = 1$.

Rational Function Solution

When $\lambda^2 - 4\mu = 0$,

$$v(\xi) = -\frac{C_2^2}{(C_1 + C_2\xi)^2} + \frac{1}{4}\lambda^2 + \alpha_0, \tag{3.21}$$

where $\xi = x + (-180\alpha_0^2 - 30\lambda^2\alpha_0 - 22\mu\lambda^2 - 76\mu^2 - \lambda^4 - 240\mu\alpha_0)t$. C_1 and C_2 are arbitrary constants.

3.2. Discussion

The solutions of the CDG (3.1) are investigated by different methods, such as Jin [32] investigated solutions by the variational iteration method, Salas [33] by the projective Riccati equation method, and Wazwaz [34] by using the tanh method. To the best of our awareness the CDG equation is not solved by the prominent (G'/G)-expansion method. In this paper, we solve this equation by the (G'/G)-expansion method. It is noteworthy to point out that our attained solutions are new and cannot be found from above author's solutions by any choice of arbitrary constants.

3.3. Graphical Representations of the Solutions

The solutions are shown in the graphs with the aid of Maple 13 in Figures 1–5.

4. Conclusions

In this paper, three types of traveling wave solutions, such as the hyperbolic, the trigonometric, and the rational functions of the Caudrey-Dodd-Gibbon equation are successfully obtained by using the (G'/G)-expansion method. Exact traveling wave solutions of this equation have many potential applications in engineering and mathematical physics.

The obtained solutions also show that the method is effective, more powerful, and simple for searching exact traveling wave solutions of the NLPDEs. The method can be applied in different types of NLEEs and it is our task in the future.

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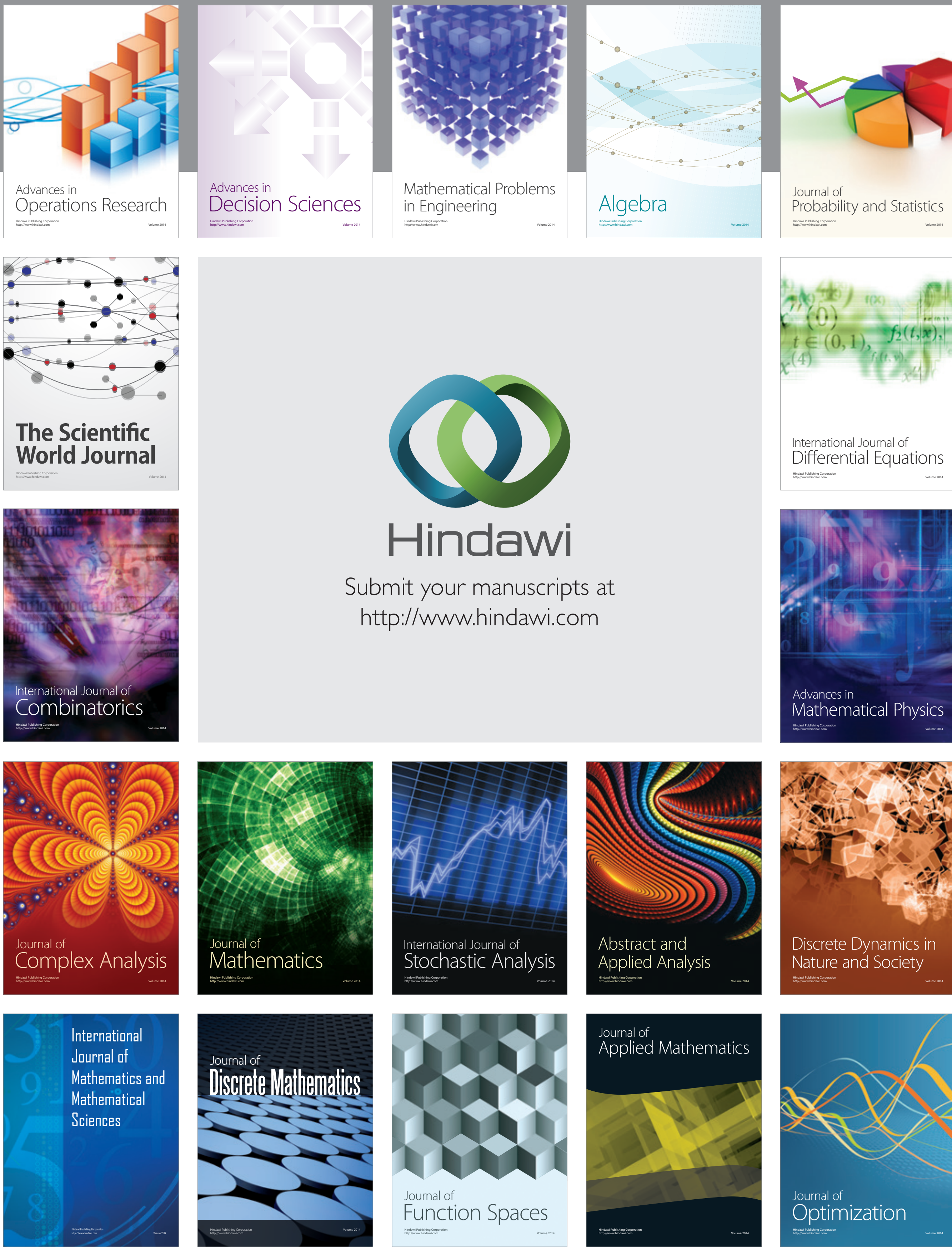
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