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A (2+1)-dimensional generalized Hirota–Satsuma–Ito equations: Lie symmetry analysis, invariant solutions and dynamics of soliton solutions

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ABSTRACT

This paper investigates the exact invariant solutions and the dynamics of soliton solutions to the (2+1)-dimensional generalized Hirota–Satsuma–Ito (g-HSI) equations. By applying the Lie symmetry technique, infinitesimal vectors, the commutation relations, and various similarity reductions are derived from the g-HSI equations. Using the two stages of Lie symmetry reductions, the equation is transformed into various nonlinear ordinary differential equations (NLODEs). After that, by solving the various resulting ODEs, we obtain abundant explicit exact solutions in terms of the involved functional parameters. These closed-form invariant solutions are successfully presented in the form of distinct complex wave-structures of solutions like combo-form solitons, dark-bright solitons, W-shaped solitons, the interaction between multiple solitons, parabolic wave solitons, multi-wave structures, and curved-shaped parabolic solitons. Furthermore, using computerized symbolic computation and numerical simulation, the physical behaviors of some obtained solutions are displayed in three-dimensional graphics. The resulting solutions are found to be useful for understanding the dynamics of the exact closed-form solutions of this model and show the authenticity as well as the effectiveness of the proposed method. Therefore, the gained solutions and their dynamical wave structures are quite significant for understanding the propagation of the excitation waves in shallow water wave models. Furthermore, using the resulting symmetries, the conservation laws of g-HSI equations have been obtained by applying Ibragimov's theorem.

Introduction

Nonlinear evaluation equations (NLEEs) are the most important tools/aspects in showing the dynamical structures of the complex physical phenomena appearing in several research fields, namely plasma physics, oceanography, optics physics, biological mathematics, chemical physics, condensed matter physics, dynamics of shallow water waves, and so on. This incites great interest among biologists, engineers, mathematicians, physicists, and many others. Many nonlinear evolution equations (NLEEs) have been solved/addressed in recent decades using efficient analytical techniques to find closed-form analytic solutions. [1–15].

The Lie symmetry technique is one of the most well-organized methods for finding exact explicit solutions to NLEEs. By analyzing these solutions, the interesting facts of complex physical phenomena can be established. These exact-invariant solutions of the nonlinear PDEs help the numerical solvers to certify the accuracy of the established solutions and allow them to check the behavior graphically as well as physically.

The Lie symmetry technique is an efficient, reliable, and robust mathematical tool in symmetry theory, with some advantages over other extremely complicated mathematical techniques used to obtain closed-form invariant solutions of the nonlinear evolution equations (NLEEs). The number of independent variables in such types of nonlinear partial differential equations was reduced by one using this technique. The Lie symmetry method has recently been used in a lot of significant research articles in mathematical physics, nonlinear sciences, and engineering physics [16–30].

The prime objective of this article focuses on finding the exact invariant solutions of the (2+1)-dimensional generalized Hirota–Satsuma–Ito (g-HSI) equations [31,32] in the following form

$$\Delta := v_t + u_{xxt} + 3(uw)_x + \gamma u_x = 0, \quad u_y = v_x, \quad u_t = w_x, \tag{1}$$

where γ is a non-zero real parameter, u is the physical field, v, w are the potentials of physical field derivatives while x, y are space-related and t is temporal coordinates. Eq. (1) is a modified form of the

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