INTRODUCTION

1.1 General

High agricultural yields from the farms of a country significantly contribute not only to the economic growth of the country but also give it a freedom from the import of the food grains from other countries. Therefore, technological advancements are essential for the improvisation of the performances of constituent elements of the agricultural sector. Timely delivery of the adequate quantum water to the fields is a primary concern of farmers to ensure high yields from their fields, and irrigation canals play a vital role to ensure this intended purpose. Additionally, these canals can also draw excess water from the wet area to deliver the same to the dry area, which enriches the agricultural diversity and enhances the productivity of en-route stretches. This, in turn, alleviates the poverty of the deprived population of the dry area at micro scale and promotes uniformity in the economic growth of a country at macro scale. At the same time, they also offer a means to protect the productive lands from the menace of frequent floods in the wet area. These man made water conveyance systems can be either lined or unlined. Lined canals are cost intensive, therefore unlined/earthen canals find a huge significance in irrigation projects.

1.2 Motivation for the Present Study

The unlined/earthen canals are cheap but incur higher seepage losses, whereas the lined channels are relatively costlier with lower seepage losses. Based on the field measurements, Kilic and Toylu (2011) reported huge water losses from lined canals, which incurred because of cracks in the canal lining developed due to settlement of the sub-grade, weed growth in lining, construction defects, use of inferior lining materials, and weathering etc. (Chahar, 2007a). Aging, constructional faults, and silting alter the magnitude of actual roughness coefficient of the lined canal surface, which may introduce a risk of flooding. Therefore, improvisation in the design of the earthen channels seems appropriate than to opt for a lined canal. The side slopes and bottom of the earthen canals are erodible, hence their design rely on the principles governing erosion of the earth materials. The side slopes inundation followed by subsequent sudden drawdown also induces channel bank failure, thus side slopes need protection under operational conditions. Flexible linings, such as riprap (with or without wire cages), vegetation, straws jacketed within wire net, and synthetic mats are applied for the protection as they offer a conducive environment for the growth of flora and fauna, shelter for the flourished and diverse range of biological species, reduced construction time and enhanced ground water recharge ability.

The design factors considered for earthen channels involve earth material characteristics, flow velocity that avoids erosion or silting, topography governing channel bed slope, and efficacy of the channel section that indicates how much the section is hydraulically or economically efficient (Chow 1973).

Not all channel shapes are equally efficient and some shapes are more efficient than others are (Anwar and de Vries 2003; Atmapoojya and Ingle 2003; Guo and Hughs 1984; Kacimov 2004: Monadjemi 1994). The best hydraulic section possessing the maximum flow velocity for a given discharge may not be the most economical (Chahar et al. 2007). Guo and Hughes (1984) further found that when the water surface level is below the channel brim or free board is included in the hydraulically efficient channel section design, a canal narrower than the hydraulically efficient section results in the minimum excavation. Thus, the most efficient sections possessing the minimum flow area or flow perimeter may not be the most economical.

Froehlich (2011a) designed a hydraulically efficient channel riveted with subround and subangular riprap to prevent the erosion of the side banks. The large-scale bank roughness increases the flow retention capability but it attenuates the surge waves because of hydropeaking (Stranner 1996). Therefore, channels having riprap riveted side slopes turn out to be beneficial for surge wave attenuation. Experimental (Canovaro et al. 2003, 2004; Pagliara and Chiavaccini 2006a, 2006b, Canovaro and Solari 2005, 2006) and numerical (Stoesser et al. 2004) studies on macro scale roughness reveal that the higher macro roughness density does not accrue to high mean flow resistance but a particular geometric arrangement of the roughness elements yield the maximum flow resistance. Thus, the macro scale roughness caused by the riprap stones on channel side slopes may not pose a serious problem.

Different types (round, subround, subangular, and angular) of riprap stones (USBR 1991) with varying physical characteristics (specific gravity, shape and size) are available for the revetment of the channel side slopes and their stability on the side slopes is expected to vary with the changing physical properties. Investigations into this aspect of the riprap stones for the minimum cost design of an earthen channel whose side slopes are lined with loose riprap and bottom is unlined is not yet available in the literature. Thus, it leaves a room for investigation into the optimal designs of an earthen channel incorporating the shape and size of riprap stones both for consideration of cost and performance optimality.

Gupta and Singh (2012) involving three different types of the riprap stones (round, subround and subangular, and angular) designed hydraulically efficient earthen channels. However, the design of earthen channels for the minimum cost involving different types of the riprap stones on side slopes with unlined bottom is not available in literature, hence this problem is worthy of investigation (Froehlich 2012). Design of trapezoidal channels imposing restrictions on channel dimensions was performed by Froehlich (1994), Das (2000), Jain et al. (2004), and Bhattacharjya (2006) etc. Attempts were also made to incorporate slope stability issue in channel design (Bhattacharjya and Satish, 2007; Reddy and Adarsh 2011) but the published literature on the design of canals, including land acquisition cost, is yet sparse, hence additional scope arises out of this gap. However, Swamee et al. (2000a) suggested for incorporating the land acquisition cost in optimization process as the canals run through many valuable lands and property areas.

The optimal design of channels constitutes a non-linear optimization problem (Jain et al. 2004; Bhattacharjya 2006). The constraints are normally been included in the objective function to form an unconstrained optimization problem (Jain et al. 2004). Several researchers (Loganathan 1991; Monadjemi 1994; Froehlich 1994; Das 2000; Froehlich 2008; Chahar 2005a; 2007a; Babaeyan-Koopaei et al 2000; Anwar and Clarke 2005) have applied Lagranges method of undetermined multiplier. Non-traditional optimization method like genetic algorithms (Jain et al. 2004; Bhattacharjya and Satish 2007, 2008; Das 2007a) have also been used extensively. Reddy and Adarsh (2011) used particle swarm optimization (Kennedy and Eberhart 1995) for the optimal design of composite channel cross-sections of lined canals but the application of particle swarm optimization for the design of earthen canals is yet due. Therefore, it is proposed to apply a relatively recent optimization technique Particle Swarm Optimization which (Eberhart and Kennedy 1995) is inspired by the social behavior of bird flocking or fish schooling that enables individual members to move synchronized (without collision) with amazing choreography. Particle swarm optimization is a swarm intelligence-based technique (Bonabeau et al. 1999; Kennedy et al. 2001) to solve global optimization problems.

The earthen channels usually carry sediment-laden flow under different operating conditions and a study relating to the effect of flowing water characteristics on channel specifications from cost and performance optimality perspectives is not available in literature. An investigation involving the aspect of flowing water characteristic on the optimal design of earthen channels offers an additional scope for the present work to undertake.

1.3 Objectives of the Present Work

A bulk of literature on optimal design studies of lined canals is available but studies relating to the optimal designs of riveted earthen canals are yet insufficient for solving problems of earthen canals. The present work involves the following objectives:

1. To evolve a procedure for the design of minimum cost trapezoidal earthen canals having side slopes riveted with riprap stones and bottom unlined using particle swarm optimization algorithm.
2. To evaluate the impact of inclusion of the costs of land acquisition and the freeboard provision in the objective function on the optimal design features trapezoidal earthen canals having side slopes riveted with riprap stones and bottom unlined.
3. Assessment of the performances of round, subround, subangular, and angular riprap stones for the design of minimum cost trapezoidal earthen channel whose side slopes are lined with riprap stones and bottom is unlined. A comparative analysis of the alternative designs obtained by

using different types of riprap stones for a given freeboard scenario is to be carried out.

4 To assess of the effects of both the clear water and sediment-laden flows near channel bottom on the optimal channel dimensions and the cost. A fixed magnitude (= 0.025) of Manning's roughness coefficient for the channel bottom was applied for clear water flow condition, whereas, the sediment-laden flow condition involved a function (Yen 2002) relating to the flow, channel and sediment characteristics (hydraulic radius, Froude and Reynolds numbers, sediment size and density, bed slope and water viscosity and density) for Manning's roughness coefficient of the channel bottom. Inclusion of this aspect adds to another novelty in the work.

5 To evaluate the impact of freeboard provision methodologies on the optimal channel dimensions and the cost. The designs of minimum cost channel without freeboard and with a fixed magnitude of freeboard are required to be determined to serve as a benchmark for the comparison purpose. An equation (Das 2008) representing freeboard as a function of flow depth was applied for creating different freeboard scenario options for the design purpose. A comparative analysis of the designs obtained for a given type of riprap stone under different freeboard scenarios was carried out.

6 The application of particle swarm optimization (PSO) needed separate programs for different types of the riprap stones (with different sets of penalty functions for each type of riprap stone) to evaluate their

performances for cost optimality. It left a scope of further investigation into the problem of minimum cost earthen channel design by applying a different/ novel optimization algorithm that can handle all riprap stones together in its single computational run to identify the most suitable type of riprap stone from cost and performance perspective. Thus, the present study involved a development of a novel optimization algorithm to serve the aforesaid intended purpose. The results obtained by the novel optimization algorithm were compared with those obtained by the application of PSO for evaluating its efficacy.

1.4 Thesis Layout

The thesis has been organized into eight chapters. They are entitled as: Introduction; Literature Review; Optimal Design of Earthen Channel: Problem Domain, Rationale, Definition and Models; Particle Swarm Optimization; Application of Particle Swarm Optimization: Results and Discussion; Development of a Novel Optimization Algorithm: Fish Shoal Optimization; Application of Fish Shoal Optimization: Results and Discussion; and Conclusions and Suggestions for the Future Work. The last chapter is followed by the relevant references cited in the thesis, publications that came out of the present work and and resume of the author.

The chapter 1 lays a foundation of the present work. It narrates the motivation and objectives of the present study. The organization of thesis outlay is also given here.

Chapter 2 reviews the literature relating to the various aspects of open channel designs and summarizes the findings of the earlier investigations conducted in relation to open channel/ canal section designs. The literature review revealed the available gap in the knowledge base and the scope of the present study has been drawn out.

Chapter 3 provides an overview of the problem domain and defines the problem statement. The problem of the optimal design of earthen channel whose side slopes were riveted with different types of riprap stones and bottoms were unlined were translated into mathematical models. The models were also transformed into dimensionless form in this chapter.

Chapter 4 presents an optimization method used for solving the problems of optimal design of earthen channels. A detailed description of the Particle Swarm Optimization (PSO) is given. The chapter describes the basic feature of swarm intelligence that culminated into the emergence of particle swarm optimization method.

Chapter 5 illustrates the procedure for the application of particle swarm optimization method to solve problem of optimal channel design. It describes the computational steps required for solving the problem. The results obtained by the application of particle swarm optimization algorithm were analyzed for assessing the impact of freeboard provision methodologies on optimal channel dimensions and cost for each type of riprap stone. Inter-comparison of results obtained for different types of riprap stones was also carried out in this chapter.

Chapter 6 presents the development of a novel optimization method, which was referred to as fish shoal optimization algorithm. The chapter narrates the capability of the novel optimization method and describes the steps involved in implementing it.

Since the novel optimization method can handle all types of riprap stones together in its single computational run to identify the most suitable type of riprap stone from cost and performance perspective, the model for the problem was revised into a new format to fit into the optimization method. The chapter 7 presents the revised model of the problem. The model was again translated into dimensionless form and the detailed procedure to implement the novel optimization method is given in this chapter. The results obtained by the application of fish shoal optimization algorithm were analyzed for assessing the impact of freeboard provision methodologies on optimal channel dimensions and cost. A comparison of the results obtained by the applications of particle swarm optimization and fish shoal optimization algorithm, respectively, were made to assess the efficacy of the novel optimization method. The performance of the novel optimization method was also discussed in relation to capability of particle swarm optimization method.

Chapter 8 summarizes the key findings and conclusions drawn out of the present investigations. The future scope of the work has also been narrated in this chapter. This chapter is followed by the list of relevant literature cited in the thesis.