INTRODUCTION

Inundations accompany the development of human society since the ancient time; they head the list of natural calamities in terms of their destructive consequences. According to data of UNESCO, inundations in the XX century killed 9 million, while earthquakes and hurricanes killed 2 million [21]. The damage caused by inundation in the world is estimated at dozens billion dollars. The areas of the territories suffering from inundations now exceed 3 million km² [31]. The population in these territories is about 1 billion.

Inundations in mouth areas of many years are much more frequent than in other parts of river basins and sea coasts. Kuban delta is not an exception. Because of the low elevations and small slopes of land surface, as well as because of diverse hydroclimatic factors, which cause catastrophic water level rises, the delta territory has been repeatedly inundated by either river or sea water. The most recent inundation took place in the winter and summer of 2002. The inundation affected populated localities, industrial facilities, and agricultural fields; roads, buildings, bridges, power transmission lines, etc. were completely or partially destroyed. The total losses were estimated at several hundreds of millions of rubles.

Thus, Kuban delta, which is an economically and environmentally important region of Russia, where various measures for protection of the territory, construction, and population against inundations have been taken since long ago, and some experience has been accumulated, was found to be not fully protected against such calamities. Such situation causes concern and requires additional studies for developing new inundation control measures and improving the efficiency of those known before. This can be done only after thorough analysis of the causes and characteristic features of the inundations that have taken place in Kuban delta and by evaluating the essence and efficiency of measures aimed to control inundations.

Various data on previous inundations in the lower reaches of the Kuban and in its delta are given in [5, 9, 10, 14–18, 24, 25, 27, 31, 32]. Almost no attention has been paid to detailed studies of the causes and characteristics of inundations in Kuban delta or to the efficiency assessment of measures to control them. Only V.I. Korovin and G.A. Galkin [4–6, 14] published the results of analysis of nearly 200 cases of large inundations in Kuban basin over 275 years (up to year 1975), their causes, and genetic types. These studies give a summary (for the basin as a whole) histogram of the within-year distribution of all types of inundations. Brief analysis of the causes and genetic types of inundations in Kuban basin is also given in [25].

The study carried out by the authors of this paper was based on materials that have been published or are available in various archives and refer to inundations in Kuban delta or on the eastern coast of the Sea of Azov, as well as on authors’ data from the archives of Kuban Mouth Hydrometeorological Station (KMS) and Geographic Faculty, MSU, collected in the recent 40 years both during and after inundations. These materials, in particular, formed the basis of first publications [10, 18], devoted to inundations in Kuban delta.

Data on the major geographic, hydrographic, and water management characteristics of Kuban delta are given in [17, 20, 22, 23, 28].
TYPIFICATION OF INUNDATIONS IN KUBAN DELTA

By inundation is meant the flooding of an area adjacent to a river or a water body, which causes material or human health damage or kills people [26]. A wider and more ecological definition of this notion is given in [7, 11]: the inundation is a temporary flooding of a territory, developed by humans for different purposes, which causes adverse social—economic and environmental consequences expressed in material and nonmaterial damage." However, the flooding of lands not involving any damage can be regarded only as a flood from a river or a water body. At the same time, the impoundment is understood as the formation of a free water surface on an area resulting from level rise of a stream, water body, or groundwater [30].

By their size and total damage, inundations are classified into small, large, outstanding, and catastrophic [26]. The category for an inundation is chosen somewhat arbitrarily—taking into account the recurrence and duration of inundations, a qualitative characteristic of the degree of inundation of the territory and the disturbance of the normal living conditions of people, or by the damage caused. In [7, 11], five categories (classes) of inundations are given clear quantitative substantiations based on the number of killed and temporarily evacuated, the inundated area, and the damage. There exist other approaches to the classification of inundations based on their social—economic damage, including those accepted by international organizations, insurance companies, EMERCOM RF, etc. [7, 8, 21].

The causes of inundations in Kuban delta are diverse. The types of inundations are defined by their causes or groups of causes. In accordance in [26], inundations in the delta can be primarily grouped into runoff, jam, and setup.

Runoff inundations are due to very large water flow in the river and delta branches. Such inundations occur in the periods of spring—summer melting of seasonal and high—mountain snow, glaciers; after abundant showers or steady precipitation; and, hypothetically, as the result of dam failure.

Jam inundations are caused by large resistance to water flow in the river and branches caused by ice jams. However, inundations of this type are very rare in Kuban delta. An important additional condition for a catastrophic flooding of the floodplain because of jams is the relatively high water flow during freshets or spring flood. Therefore, it is methodologically reasonable to separate the category of runoff—jam inundations or inundations of a mixed-type.

Setup inundations are caused by strong wind—induced water setups from the Sea of Azov.

Inundations in Kuban delta can also be divided into those caused by natural or anthropogenic factors, or may be of a mixed origin.

In addition to the inundation groups mentioned above, inundations caused by heavy showers under certain orographic, hydrogeological, and other features of individual delta territories may appear without any connection with a river or other water objects. Abundant rainwater does not completely infiltrate into the soil and is discharged into hydrographic network (because of its shower character) or causes a considerable rise in groundwater table (because of the large volume of previous precipitation). In some cases, rainwater evacuation is hampered by the small slopes of delta land areas, protection dikes, and channel banks. This may cause inundation of lands in the delta (and the formation of powerful rain flows on them), weakening of soils, and even the formation of landslides.

Table 1 gives data on inundations in Kuban delta, for which sufficiently full and reliable data are available in the literature and KMS archives. As can be seen in this table, inundations in the Kuban River are most often due to the passage of floods through the river with simultaneous existence of ice jams in river channels in the nearshore area. During the recent hundred years, inundations of the mixed and jam types account for ~50—60% of all cases, while runoff inundations account for ~35—45%. About 10% of the cases are two catastrophic setup inundations in 1914 and 1969.

RUNOFF INUNDATIONS AND MEASURES FOR THEIR PREVENTION

The cause of runoff floodplain flooding and inundation is an rapid rise of water level in the river channel above a critical level \( H_{cr} \), caused by maximal water flow in the river \( Q_{max} \). Note that maximal annual water flow values can be recorded in Kuban delta head in any time during the year, though they are most common in May—June (~40% up to 1973) and least common in September (<1%). The recurrence of \( Q_{max} \) in the warm season decreases toward the mouths of the main delta branches—the Protoka and the Kuban [20, 22]. This is due to the inflow in the Kuban branch of water from left tributaries, which have autumn—winter flood regime (earlier, through the Kurkui arm, and since the late 1960s, through the Varnavinskii canal), typical of which are intense water withdrawal (in warm season) for irrigation and watering, flooding over the floodplain and plavni during freshets and spring flood, and runoff distribution in the bifurcation points of branches, etc.

Water level in the river or a branch rising above the elevation \( H_{cr} \) causes the flooding of the floodplain and (in a critical case) economic and social facilities in it, i.e., an inundation. River water overflow and runoff inundations depend on the value and duration of the maximal water flow in the river, the carrying capacity of the channel and the leveed part of the floodplain, and the morphological features of the floodplan. These factors may change from year to year. This is facilitated by many—year variations in maximal values.