a) Flooded fields

b) Flooded bare soils

c) Flooded grassland along a river bank

Figure 13 Flooded surfaces in the study area

Rice paddies (Figure 12), when flooded in the early stage of rice cropping, are surrounded by very small dykes, and are characterized by varying size, almost rectangular shape and lack of regular pattern. Therefore adjacent paddies, when flooded, may be easily confused with groups of artisanal shrimp ponds.

Three potentially flooded surfaces occur in the study area: agricultural fields, bare soil and grassland along rivers and creeks (see Figure 13).

Flooded agricultural fields (Figure 13a) have regular shape; their appearance on SAR images is indistinguishable from shrimp ponds or rice paddies.

Bare flooded soils (Figure 13b) are characterized by irregular shape and low response intensity, and are located along rivers and creeks. This position may cause them to be confused with shrimp ponds whenever their extension is small and their irregular shape cannot be appreciated.

Flooded grassland along rivers and creeks (Figure 13c) is easily misinterpreted as artisanal shrimp farms or small rice paddies, while dense flooded vegetation may only be confused with rice paddies.

The analysis of size, shape and pattern of water-covered surfaces allows an easy identification of large water bodies and water body associations, such as reservoirs and industrial shrimp farms. Difficulties arise in recognizing artisanal shrimp farms, due to their limited size. Small flooded surfaces may also lead to misidentification errors.

Theoretically, a water body is detectable in an image even if its surface is smaller than a pixel's, because of the saturation effect. When a portion of the ground corresponding to a pixel (12.5 x 12.5 m) contains a small and very low-reflective feature, the pixel's value is low as well, and can easily be identified as a water-covered surface. Unfortunately its shape and pattern are not defined, so it is impossible to infer its nature.

Thus, even if it is possible to identify water bodies up to 10 x 10 m in size, a shrimp pond must be at least a few pixels wide to be recognized as such. Even so, the identification is uncertain.
The artisanal shrimp ponds are generally small, and the surrounding dykes are not always evident. Often these shrimp ponds are also irregularly grouped, and consequently they may be confused with paddies or small flooded surfaces.

Thus, to confirm the identification of artisanal shrimp farms, the operator must analyze their location and previous land use, as explained in the following sections.

Location of shrimp farms

Shrimp farms require brackish or salt water. Consequently, shrimp ponds must be located along rivers and creeks, in proximity to lagoons. A system of channels carries water from the river through the connected ponds, and then back to the river.

The topographic maps of the study area, produced in 1984, show that the majority of shrimp ponds have been built over uncultivated land, such as mangroves and swamps. In some cases the ponds are located over former forest and coconut plantations; only rarely has there been a conversion of land use from rice paddies to shrimp ponds.

Thus the former land use may help in distinguishing between shrimp ponds and other water-covered surfaces.

Water coverage throughout the year

Another characteristic that differentiates shrimp ponds, paddies and flooded surfaces is the water coverage throughout the year. Shrimp ponds usually are covered by water, while paddies are flooded only during the early stage of rice growth.

Sri Lanka has a tropical climate, and therefore the stages of rice cultivation may not be related to the seasons. Thus all phenological stages of rice can be present at the same period of the year. Consequently, it is not possible to distinguish between paddies and shrimp ponds by a temporal criterion only: whenever a SAR image is acquired, both flooded and dry rice fields may simultaneously occur on it.

The presence of flooded surfaces is instead related to the occurrence of rainfall, which is in turn seasonal. By acquiring SAR images in a dry period of the year it is possible at least to minimize the occurrence of flooded surfaces, thus improving the identification of shrimp ponds.

The rainfall over the study area in 1998 is shown in Fig. 14. From the graph it is evident that the SAR image acquired in April 1996 corresponds to a rainy period, while the two ERS SAR images acquired in 1998 (Table 2) correspond to a dry (July) and a wet (October) period, respectively. By comparing the water-covered surfaces identified in the two 1998 images, it is thus possible to improve the discrimination between shrimp ponds and flooded surfaces.

Image analysis procedure

The inherent characteristics of shrimp ponds and of other kinds of water-covered surfaces in SAR images, as indicated in the previous paragraph, allow an image analysis methodology to be designed in order to identify and map shrimp farms.

All water-covered surfaces have a peculiar appearance in SAR images. They may be easily identified and mapped using automatic classification techniques. It is then necessary to recognize shrimp ponds among the different kinds of water bodies.

Unlike other water bodies, shrimp ponds are delimited by dykes. The dykes are identified in the image using automatic boundary detection and classification techniques. Therefore to identify shrimp ponds it is necessary to search the images resulting from classification of water bodies for evidence of dykes in the strip of terrain surrounding the water-covered surfaces. This is done by means of proximity analysis techniques.

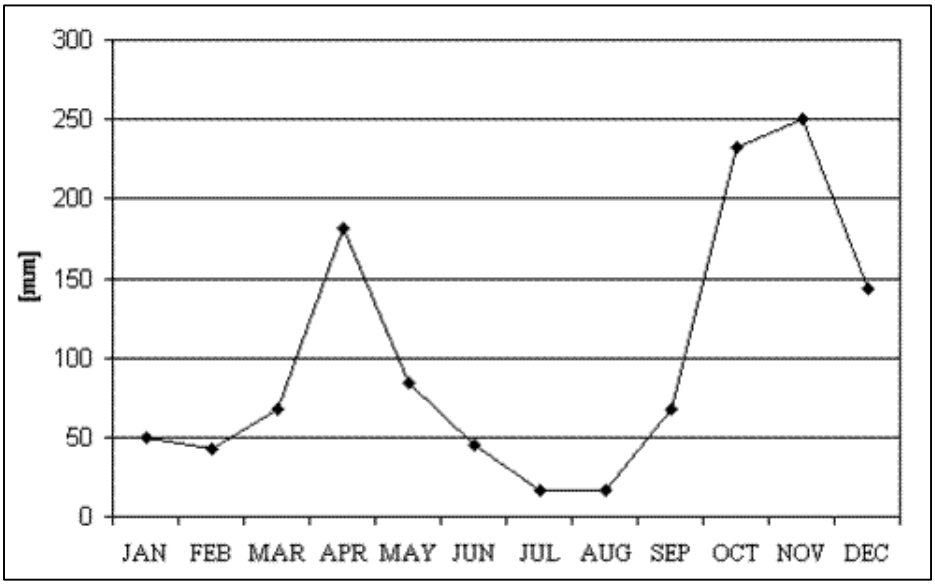

Figure 14 Monthly rainfall at Puttalam (Sri Lanka), 1998

This approach produces images containing water-covered surfaces and the terrain surrounding them, showing strong-reflecting and weakly-reflecting boundaries. These images are the result of automatic procedures, and summarize the information on shrimp farms that can be obtained from a SAR image. They are thus named "summary images".

The summary images must then be visually analyzed by an operator, who identifies shrimp farms among the other water-covered surfaces by means of visual interpretation techniques. These include the evaluation of shape and pattern of water bodies and of the presence of well-defined boundaries surrounding them.

Finally, a confirmation of the identifications is made by examining the location and previous land use of the selected areas, obtained from topographic maps.

The analysis procedure is summarized in Figure 15. The steps are discussed in the following paragraphs.

Pre-processing

The first step of the procedure aims at preparing the data for the analysis proper.

The study area is covered by pairs of frames that must be mosaiced, i.e. attached together to form a unique image, from which the study area is selected and extracted. The images of the study area must then be filtered to minimize the typical noise of SAR images, called *speckle*.

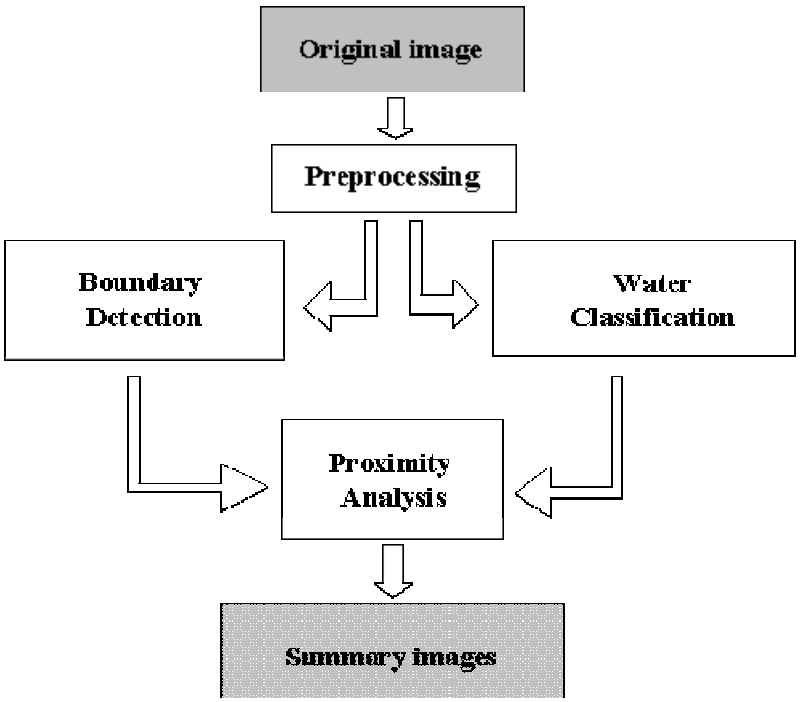

Figure 15 SAR image analysis procedure

NEXT PAGE