SATELLITE REMOTE SENSING FOR NUCLEAR POWER PLANT ENVIRONMENT ‘S ANALYSIS "

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ABSTRACT

Geospatial and information technologies represent a complementary source for ground-based data.The synergistic use of multi-temporal , multi-spectral and multi-resolution remote sensing data offers the possibility of environment monitoring in the vicinity of nuclear power plants (NPP). Advanced digital processing techniques applied to several LANDSAT TM ,ETM, MODIS and ASTER data are used to assess the extent and magnitude of radiation and non-radiation effects on the water , near field soil, vegetation , air and population exposure for Nuclear Power Plant Cernavoda, Romania . Thermal discharge water from nuclear reactor cooling is dissipated as waste heat in Danube-Black -Sea Canal and Danube River. Water temperature distributions captured in thermal IR imagery are correlated with meteorological parameters. This is one of the negative factors , which seriously disturbs the thermal balance of the water basins and leads to irreversible environmental changes. Additional information regarding flooding events and earthquake risks is considered .

Keywords: Satellite remote sensing, Thermal plume, Nuclear Power Plant Cernavoda, environment, Romania.

Introduction

Cernavoda Unit 1 power plant, using CANDU technology, having 706.5 MW power, is successfully in operation since 1996 . Cernavoda Unit 2 which is currently under construction will be operational in 2007.The facility is designed to meet the stringent safeguards requirements imposed by the International Atomic Energy Agency. Due to the further integration of the Romanian industry in the European structures which will be achieved through the sustainable development of the energy sector, during next years will be continued the construction of the Cernavoda NPP-Units 3, 4 and 5 on a step by step base, in compliance with the national strategy for the Romanian nuclear power development. This will increase the contribution of ‘clean energy' to electricity production in Romania, reducing

CO_2 and other polluting emissions, as well as the volume of solid waste resulting from burning coal in, as well as reducing the dependence of Romania on external suppliers of primary resources, mainly natural gas and oil, thus contributing to the increase of the ‘Security of Energy Supply” of Romania and Europe. Anyway, renewable are better options than nuclear power for meeting the Romanian needs for energy without the risk of disastrous accidents for the population.

Both the Cernavoda CANDU Unit 1 and 2 NPPs are designed for the meteorological conditions specified for the Site: normal and extreme values for ambient temperature, wind speed, amount of precipitation (rain and snow) and level of humidity. The NPPs are also designed to withstand extreme meteorological conditions (e.g., extreme wind and rain).The Cernavoda Site grade level has been established higher than the highest credible flood water level, so there is no danger of flooding from either the DBS Canal or Danube River Both Cernavoda NPPs are designed to resist the effects of earthquakes. Some geological and seismological investigations indicated that there are no large regional or undeveloped linear geomorphic features on or near the Site and no major or active faults are there, but last seismological studies considered as seismic risk was underestimated [1].

The environmental advantages of nuclear energy technology over alternative means of large-scale energy production are many. Non-radioactive pollutants of the atmosphere like as release of greenhouse toxic gas and toxic atmospheric emissions are insignificant in comparison with fossil fuel and biomass burning , destruction of habitat and use of land is very small in comparison with hydro, wind, or solar power. The main environmental issues affecting the broad acceptability of nuclear power are the emission of radioactive materials, the generation of radioactive waste, and the potential for nuclear accidents. All nuclear fission reactors, regardless of design, location, operator or regulator, have the potential to undergo catastrophic accidents involving loss of control of the reactor core, failure of safety systems and subsequent widespread fallout of hazardous fission products. While such accidents are infrequent, the consequences are severe and involve effects on human health, the environment and the economy. Risk is the mathematical product of probability and consequences, so low-probability and high-consequence accidents, by definition, have a high risk.
This paper will consider only non-radiological aspects of the thermal water emissions in the environment.

Satellite Remote Sensing for Assessment of Nuclear Power Plants Environment

Remote sensing is the science and art of acquiring information (spectral, spatial, temporal) about material objects, area, or phenomenon, without coming into physical contact with the objects, or area, or phenomenon under investigation. Without direct contact, some means of transferring information through space must be utilized. In remote sensing, information transfer is accomplished by use of different wavelength bands : Optical wavelength (0.30-15.0 mm), Reflective portion (0.38-3.00 mm), visible (0.38-0.72 mm) , Near Infra Red (0.72-1.30 mm), Middle Infra Red (1.30-3.00 mm) , Far IR (Thermal, Emissive)- (7.00-15.0 mm), Microwave region (1mm to 1m) of electromagnetic radiation. The major factors affecting water quality in river and canal waters, seas and oceans are : suspended matters; chlorophylls (algae); chemicals substances; dissolve organic matter (DOM); nutrients; pesticides; thermal releases; and oils. Suspended sediments (turbidity), chlorophyll, DOM and oils affect the surface water in their spectral properties. They change the spectra of reflected solar and/or emitted thermal radiation from surface waters. Such changes in spectral signals from surface waters are measurable by remote sensing techniques from many platforms. The strength of remote sensing techniques lies in their ability to provide both spatial and temporal views of surface water, which is not possible to be assessed from in-situ measurements [2,3].These water quality parameters can be quantified by using remote sensing techniques. This will allow us to plan a management formulation in order to reduce movement of substances from catchments to water bodies, and thus reducing the effect of the pollutant on water quality. Quantitative determination of the amount of various water quality parameters is very useful for water management purposes. The basic idea of remote sensing of water quality is to use the difference in water color or, more precisely, the difference in spectral reflectance to estimate the amount of dissolve and suspended matter in the water. The relationship between spectral signature of the water and the amount of the substances in that water is still an active field of research.

Temperature is an important of environmental parameter, which is frequently studied by several sciences, such as, physical oceanography, marine chemistry and marine biology. River or Sea Water Surface Temperature ,in many cases, is closely related to the deeper layers of the water masses below the surface. The derivation of water body surface temperature from satellite measurements has been a focus of numerous studies. Water temperature is a critical water parameter, since it influences directly the amount of dissolved oxygen that is available to aquatic organisms. Water temperature affects the rates of all chemical and biological process. In general, as the temperature of water increases, the amount of oxygen dissolved in the water decreases and there is a tendency for the amount of pollutants to increases. Water surface temperature is an important geophysical parameter, providing the boundary condition used in the estimation of heat flux at the air-surface water interface. On the global scale this is important for climate modeling, study of the earth's heat balance. Methods for determining water temperature from satellite remote sensing include thermal infrared and passive microwave radiometry [4, 5].Thermal infrared instruments that have been used for deriving surface waters temperature include Landsat TM and ETM (thermal bands), Advanced Very High Resolution Radiometer (AVHRR) on NOAA Polar-orbiting Operational Environmental Satellites (POES), and Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA Earth Observing System (EOS) Terra and Aqua satellites, Along-Track Scanning Radiometer (ATSR) aboard the European Remote Sensing Satellite (ERS-2), the Geostationary Operational Environmental Satellite (GOES) Imager, ASTER. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a research facility instrument launched on NASA’s Terra with three spectral bands in the visible and near-infrared (VNIR), six bands in the short-wave-infrared (SWIR), and five bands in the thermal infrared (TIR) regions respectively. The spectral bandpasses of the TIR bands are very suited for surface water temperature mapping. The primary objective for the ASTER mission is to obtain high-spatial-resolution (local, regional, and global) images of the Earth , namely :VNIR (15m), SWIR (30m), and TIR(90m) [4]. During last years thermal infrared data become very useful for global climatic models, global warming monitoring, detection of thermal discharges in the environment .Thermal infrared surface water temperature measurements have a long heritage (~20 years) [6,7]. They are derived from radiometric observations at wavelengths of ~3.7 µm and/or near 10 µm. Though the 3.7 µm channel is more sensitive to surface water temperature , it is primarily used only for night-time measurements because of relatively strong reflection of solar irradiation in this wavelength region, which contaminates the retrieved radiation. Both bands are sensitive to the presence of clouds and scattering by aerosols and atmospheric water vapor. For this reason, thermal infrared measurements of surface water temperature first require atmospheric correction of the retrieved signal and can only be made for cloud-free pixels [8]. Thus, maps of surface water temperature compiled from thermal infrared measurements are often weekly or monthly composites which allow enough time to capture cloud-free pixels over a region [9].

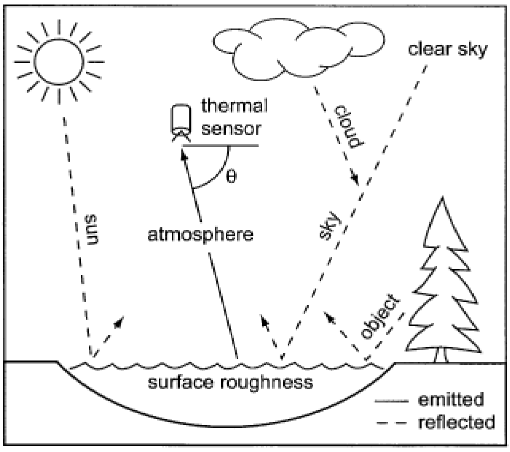

Fig.1. *Sources of emitted and reflected radiation in thermal remote sensing of rivers*

The radiation emitted from a surface at a given wavelength in the thermal infrared is a function of its temperature and emissivity (Figure 1). Since the thermal property is representative of upper several centimeters of the surface and due to the very nature of this radiation, it proves to be complementary to other remote sensing data and even unique in helping to identify surface materials and features and thermal emissions in the environment, geothermal anomalies, rock types, soil moisture, etc [8,9]. Thermal remote sensing reserves immense potential for applications in the fields of geology, natural hazard management, environmental science, hydrology, forestry and urban planning.

Test Area And Data Used

The Cernavoda NPP Site is located in Constanta County, latitude 44.3 °N and longitudes 28.01 °E in the Dobrogea Region (Figure 2). The nuclear facility lies about 2 km southeast of the town of Cernavoda, in the lower Danube region, near the Black Sea.

The site is located between the Danube River and the Danube-Black-Sea(DBS) Canal. The Danube River , the second largest river in Europe, (1,075 km length bordering Romania) drains the whole of Romania and completes its 2857 km course through nine countries in Romania's Danube Delta) to its mouth on the Black Sea. In the 1970s, a new dam raised the Danube's level and eased navigation through the Iron Gates. The river has become an important source of hydroelectric power and of irrigation water for farming. Romania's rivers are mainly tributaries of the Danube.

The Danube-Black Sea (DBS) Canal (64.2 km long), between Cernavoda and Agigea-Constanta was opened to traffic in 1984. Danube River waters temperature depends on the climate of the various parts of the basin. In the Romanian sector summer temperatures vary between 22 ° and 24 °C, while winter temperatures near the banks and on the surface drop below freezing, but the Danube never freezes entirely, because the current is turbulent. During severe winters the lower courses, however, become icebound. Between December and March, periods of ice drift combine with the spring thaw, causing floating ice blocks to accumulate at the river islands, jamming the river's course, and often creating major floods.The natural regime of river runoff changes constantly as a result of the introduction of stream-regulating equipment, including dams and dikes. The mineral content of the river is greater during the winter than the summer. The content of organic matter is relatively low, but pollution increases as the waters flow past industrial areas. The river's chemistry also changes as city sewerage and agricultural runoff find their way into the river. The NPP gets its cooling water from the DBS Canal. „Most of the time the cooling water is returned to the Danube River, but in winter it can be released into the Canal, so that the warmed cooling water can be used to avoid freezing at the intake . In the vicinity of the NPP diverse industrial and other hazardous activities (pipelines for petroleum and natural gas) are going on.

The Site was not a greenfield site - it previously contained a limestone quarry with a cement plant. About 220 000 people reside within 30 km of the Site. The terrain of the Cernavoda area is generally flat but there are hills and low mountains especially to the South. There is also a hill between the Cernavoda NPP and the town of Cernavoda, creating a natural barrier between the site and the town. The climate is continental with a Mediterranean-like influence from the Black Sea. Summers are hot and dry and winters are moderate, with some snow.

The major aquatic ecosystems in the Cernavoda area are the Danube River, the Danube-Black Sea (DBS) Canal, and a series of ponds and lakes. These interconnected systems are characterized by complex trophic structures, starting with primary producers, through primary and secondary consumers, to decomposers. The most important primary producers are algae and aquatic macrophytes. The primary consumers are zooplankton (rich in rotifers), invertebrates (including zebra mussels), and some plant-eating fish, such as carp, bream and roach. Primary consumers also include several species of water birds. Some invertebrates act as secondary consumers, as do predacious fish, such as pike, perch and sheat fish, which is a native species of large catfish. The same is true for various species of frogs, snakes, birds and mammals that feed on aquatic animals. Among the most important decomposers are benthic invertebrates, fungi and bacteria, which make nutrients available for recycling. All the systems have been heavily influenced by human activity, having been settled by the ancient Greeks, the Romans and successive civilizations. The terrestrial environment near the

NPP Site is dominated by simple agricultural ecosystems interspersed with some more complex semi-natural systems.

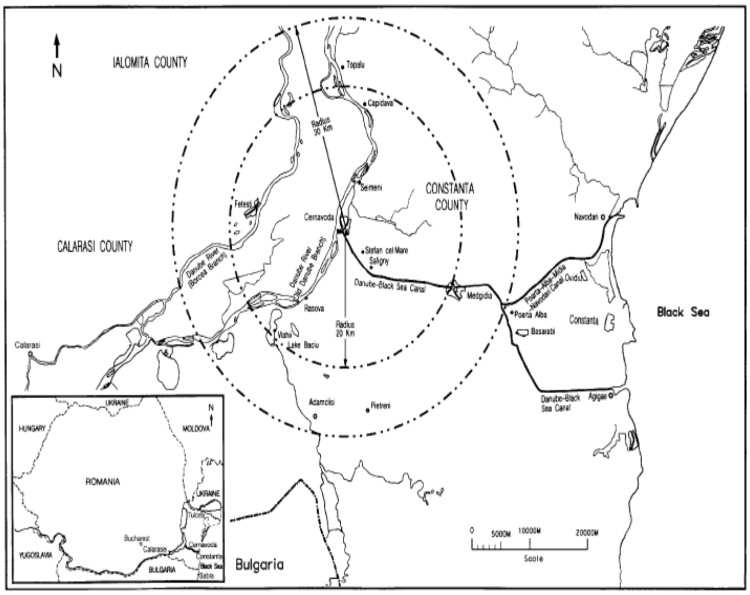

Fig. 2. *Cernavoda NPP and major population centers*

Typical animal species include the hare, hedgehog, roe deer, grey partridge and quail – all capable of thriving in close proximity to people. The Site is not a staging area for migratory birds. The Cernavoda NPP Site is located at the convergence of several transportation systems. There are both nationally and internationally important waterways - the Danube River and the DBS Canal. Road and railway networks connect the town of Cernavoda with locations to the North and South along the Danube River. Within a 30-km radius of the Cernavoda NPP Site, there are several historical monuments and archeologically significant ruins, some of which date back to Greek and Roman times. There are

also four nature reserves, intended to protect species of native vegetation. There are no national parks, World Heritage Sites or World Biosphere Reserves near the Site. There is a museum in Medgidia, an art collection in Topalu and folk architecture sites in several villages. None of these features are located sufficiently close to the NPP to be disturbed by its operation. There is little tourism in the Cernavoda area.

The investigations were focused on estimating of thermal plume releases from Cernavoda NPP Unit 1 from satellite data and in-situ measurements of water surface temperature of Black Sea-Danube Canal and its entrance zone in Danube River. The following data were used : Landsat TM 24/07/1998, Landsat ETM 20/08/2002 ; MODIS data of 3/08/2001, 18/03/2002, 16/09/2002 , 12/06/2003, 12/08/2003, 20/09/2003 , 16/03/2004 ; ASTER data 31/05/2003 .

Some in-situ additional measurements of the physico-chemical parameters of the Black Sea-Danube Canal and Danube River water and the composition and biomass of the biota.

The images were geometrically corrected to fit a topographic map with a scale of 1: 50 000 and 1:100 000, on which vectors were digitized for the subsequent geocoding of the satellite images. Calibration and radiometric corrections were done .

Methods

The methodology used the integration of data recorded by different satellite sensors through newly developed algorithms for water thermal plume releases monitoring in the hydrologic network in the vicinity of Cernavoda NPP as well as to monitor the environmental state of surface water in Black Sea-Danube Canal and Danube River.

Landsat TM , ETM ,MODIS and ASTER data were processed with PCI's EASI/PACE and ENVI 4.1, ILWIS 3.1 and IDL software . Geometric and atmospheric corrections were applied. Fusion of different sensors data allows for a better interpretation of the influence of the thermal river plume due to Cernavoda NPP on the local river ecosystem : in a distance of up to 30 km from the main heat source .

The long-term imaging of Cernavoda and surroundings area by satellite-born sensors allows for statistical analyses with respect to the occurrence of certain phenomena of interest.

Satellite data in thermal Infra Red range may be converted to temperature based on the conversion coefficients appended on the data function of thermal sensor used .

Was selected a valid data range with upper and lower limits to identify pixels that were within a normal temperature range (non-plume pixels), and those that were warmer than normal (designated as plume pixels). Land pixels were flagged with values of zero and excluded from the analysis. The average temperatures were calculated for pixels in the plume and non-plume areas. The number of pixels in the plume was used to estimate the areal extent of the plume assumes. We demonstrate that Landsat TM and ETM ,MODIS and ASTER satellite remote sensing images can be used to determine warm water discharge from Cernavoda NPP. Was also analyzed the seasonally variability of the thermal plume by using satellite data and in-situ data measurements.

The classification of surface water temperatures was obtained from two operational classification standards and a combination in order to be most suitable when remote sensing data is used. In most cases, the classification is possible even without concurrent ground truth data. This indicates that operational classification with remote sensing data is possible. The classification accuracy ranges from 76% to 90%. The main advantage of remote sensing over the traditional surface water monitoring method based on water sample collection is its good spatial and temporal coverage. Monitoring can be carried out several times per year and rivers not included in the traditional sampling can be also monitored. River waters require a specific algorithm to take into account the differences in water constitute and their optical properties at different locations and times. These differences are caused by several factors such as fluctuations in winds, river discharge, sediment load, primary production and phytoplankton species type. As a result, in-situ data must be required at the same time as the satellite overpass to calibrate algorithm specific to the site. The algorithms developed for a specific site will not be accurate for other geographical locations. However, the method of algorithm development can be applied anywhere. Were developed the algorithms for specific site of Cernavoda NPP area waters, but with different times between satellite overpass and in-situ measurements.

The resulting surface waters temperature maps retrieved from the imagery after application of the statistical algorithm show detailed information on the variation in temperature in the Black Sea- Danube Canal and the inflow in the Danube River.The limited amount of in-situ measurements also influences the result of statistical approach.

Results

In Cernavoda Nuclear Power Plant area, all waste heat resulting from CANDU reactors cooling system is entering in hydrological canals nearby and some of heat is lost to the atmosphere via evaporation, convection of sensible heat and thermal radiation. Correct prediction of temperatures in the cooling canals requires accurate meteorological data for calculation of energy losses to the atmosphere. Verification of the temperature predictions requires direct water temperature measurements, which are also used to verify satellite temperature retrievals. Nearby surface temperature of water and upper-air meteorological data are used to compute energy losses to the atmosphere. The thermal inertia of large bodies of water such as the canal system makes the computed temperatures insensitive to hourly fluctuations in air temperature, humidity and winds. Hour-to-hour variations in wind speed and direction produce some changes in thermal plume movement and dimensions.In order to get the spatial and temporal distribution of the warm water discharge from Cernavoda NPP and to characterize the thermal plume satellite remote sensing data were used.Warm water discharge could have consequences on the ecology of Black Sea –Danube Canal and Danube River. Regarding fishery presence in the hydrological network in the vicinity of Cernavoda Nuclear Power Plant in Black Sea –Danube Canal and Danube River , a survey of pertinent literature shows that fish will move if they find the water temperature intolerable, but they can remain in a zone with tolerable temperatures if they are capable to acclimatizing to it.

Fig. 3. *PCA classifications on Landsat TM (24/07/1998) Cernavoda NPP test area*

Water temperature distributions captured in thermal IR imagery are correlated with meteorological parameters. Additional information regarding flooding events and earthquake risks is considered . Before the operation of the Cernavoda NPP, by numerical modeling was predicted that the power station could affect the region 5 km from the power station. In the immediate vicinity of Unit 1 reactor , the water temperature plume can register a difference of 9 ^{o}C . During the winter , the thermal plume is localized to an area within a few km of the power plant, and the temperature difference between the plume and non-plume areas is about 1.5 ^{o}C. During the summer and fall , there is a larger thermal plume extending 5-6 km far along Danube Black Sea Canal, and the temperature change is about 1.0 ^{o}C. During summer, the stratified waters confine the warm thermal plume in the upper few meters of the water column. The discharge of the warm water further increases the surface water temperature, which enhances stratification. Variation of surface water temperature in the thermal plume is analyzed. The strong seasonal difference in the thermal plume is related to vertical mixing of the water column in winter and to stratification in summer. Hydrodynamic simulation lead to better understanding of the mechanisms by which waste heat from NPP Cernavoda is dissipated in the environment. Studies on the environmental impact of warm water discharge have been undertaken for many power plants , have been reported that thermal discharge increased water temperature of the body water reservoirs. The influence of the thermal plume on phytoplankton growth should also be further investigated. Before the operation of the Cernavoda NPP, by numerical modeling was predicted that the power station could affect the region 5 km from the power station. Principal Component Analysis (PCA) based on Landsat TM and ETM data in surface water monitoring of Cernavoda test area have been done to identify the temperature and turbidity changes .

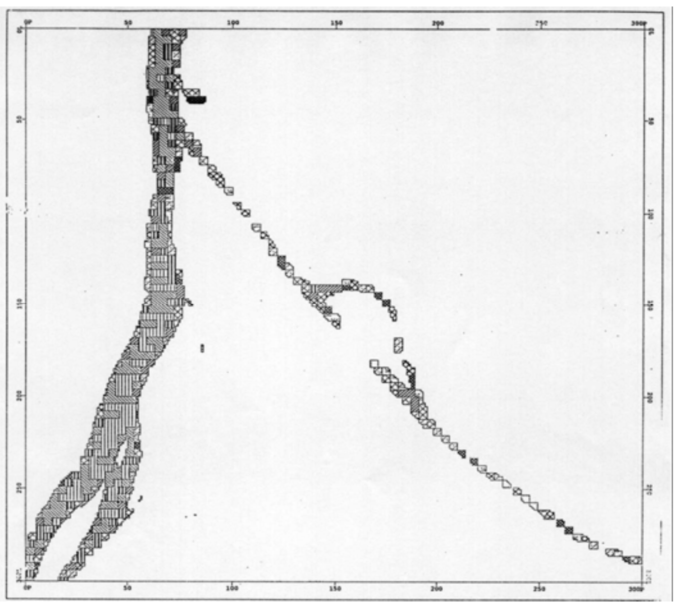

Fig. 4. *Water temperature map for Cernavoda area Landsat ETM 20/08/2002*

Figure 3 presents a PCA classification on Landsat TM image 24/07/1998 for NPP hydrologic network Cernavoda NPP test area. Figure 4 shows a water temperature map of Cernavoda canals derived from Landsat ETM 20/08/2002 image. Similar analyses were done on MODIS and ASTER data.

Figure 5 also presents a temperature distribution map in a nearby area on Cernavoda NPP based on MODIS data 20/09/2003.

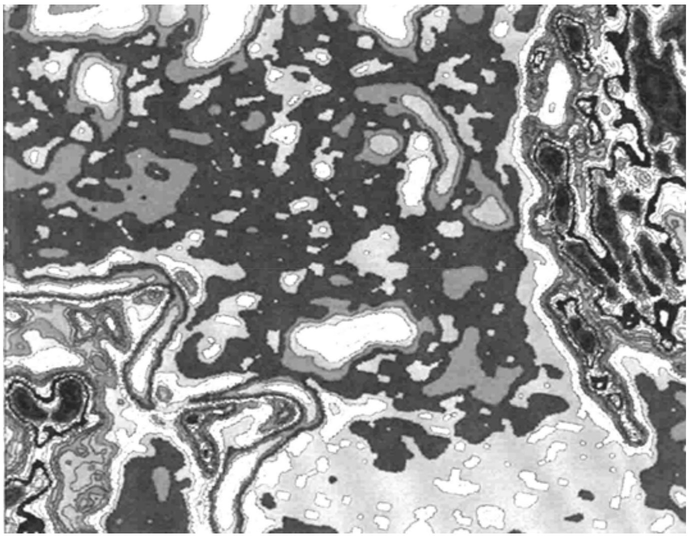

Figure 5.Water temperature distribution map in a nearby area on Cernavoda NPP (MODIS 20/09/2003).

Conclusion

The great amount of heated water thrown off permanently in the Cernavoda NPP hydrological network canals is one of the negative factors , which seriously disturbs the thermal balance of the water basins and leads to irreversible environmental change, having impacts on the degree of algae growth and the increase of water temperature.The main aim of this research was to develop the remote method of influence on nuclear power plant on the thermal state of the nearby canals and Danube river and to compare it with different natural inputs of heat.Was presented some results from multisensor satellite imagery regarding thermal discharge from nuclear reactor cooling which is dissipated as waste heat in Danube-Black -Sea Canal and Danube river. Water temperature distributions captured in thermal IR imagery were positive correlated with meteorological parameters and in-situ monitoring data.

High-resolution thermal imagery of Nuclear Power Plant Cernavoda warm water from cooling systems can lead to better understanding of the behavior of the transport and dissipation of waste heat in Black Sea –Danube Canal , Danube River and finally in the neighborhood environment.

The present study will be useful in determining the thermal release water distribution in Cernavoda NPP due to Unit 1 , prior of its increased capacity by construction of Unit 2 and future Units 3, 4 and 5 CANDU reactors.

The results of this work may also help in designing future ecosystem impact assessments.

The future use of NOAA AVHRR , ENVI , SAR ERS-2 images will provide a basis for water thermal plume analysis, as well as Total Suspended Matter (TSM) and chlorophyll Chl-a concentrations on monthly, seasonal and the most extreme conditions basis , very useful for decision makers .

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