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Technical Note

ENVIRONMENTAL IMPACTS CAUSED BY PADDY FIELD MANAGEMENT

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ABSTRACT: Paddy fields occupy large areas and are an important component of the cropped areas in the Asian Region. In this study, the environmental impacts caused by paddy field management are investigated and studied. It is observed that paddy fields cause both beneficial and adverse effects on the environment. The beneficial effects consist of flood retardation, sediment retention and recharge to groundwater. Important adverse effects are contamination to water resources, effect on human health and methane emissions. Steps needed to mitigate the adverse effects from paddy fields are also considered. These include understanding the water balance components for efficient water management, provision of surface and subsurface drainage systems and recirculation of drainage water. Water quality aspects, which need to be considered while recirculation drainage water and final disposal of the drainage water, are also studied. While all aspects of water quality are important, in general water quality aspects, which need attention, appear to be the total nitrogen and pesticide residues. Further studies are needed to manage both these constituents of the drainage water.

Keywords: Paddy fields, environmental impacts, field layout, drainage, water quality

INTRODUCTION

Rice/paddy is an important food crop in many countries around the world, especially in the Asian Region. In several countries of the Asian Region, large areas are under rice cultivation. Most of the rice is cultivated under lowland conditions with standing water on the land surface during considerable part of the crop growth period. At most of the locations, as the rainfall is not evenly distributed, fresh water resources are used for irrigating the crop. Among all the food crops, rice consumes the maximum amount of water.

For successful crop production, application of various chemicals is needed for different purposes. Fertilizers are applied for crop nutrition and herbicides are applied for control of weeds in the fields while insecticides and pesticides are used for control of crop pests and diseases. A part of these chemicals finds their way to different water bodies and act as contaminants to the water resource systems.

Because of the standing water on the land surface for long periods, lowland rice cultivation has been a source of health problems to humans residing in the area. Paddy fields were instrumental for causing several vector borne diseases like Japanese encephalitis, malaria and schistosomiasis. However, at present the occurrence and spread of these diseases are rather different in various countries.

In spite of the adverse effects, rice fields perform several beneficial functions. They retain a considerable part of the rainfall and have a moderating effect on runoff. They also retain a considerable part of the sediment produced in the uplands. As water stands in the rice fields for long periods, it helps in recharging groundwater aquifers. An individual farmer is generally interested in getting maximum crop yields from his fields and is not very much concerned about the overall environmental impacts that could result from rice cultivation. The water resources engineer or the environmental scientist needs to consider such impacts and plan for reducing the adverse effects. In this study, the overall environmental impacts both from the beneficial and adverse viewpoints along with the measures adopted for reducing the adverse impacts of rice cultivation are evaluated.

ENVIRONMENTAL IMPACTS

Rice fields are responsible both for adverse and beneficial environmental impacts. These could be listed as follows:

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Adverse Effects

- Contamination of surface water resources
- Contamination of groundwater resources
- Health aspects
- Eutrophication of water bodies
- Methane emission into atmosphere
- Generation of agricultural waste products
- Air pollution due to burning of agricultural wastes

Beneficial Effects

- Crop production
- Retention of rainfall to moderate floods
- Retention of sediment produced as a result of soil erosion in uplands
- Groundwater recharge

PADDY FIELD MANAGEMENT FOR ENVIRONMENTAL PROTECTION

A series of measures need to be implemented in paddy fields so that the adverse effects on environment could be minimized. The various aspects of paddy field management for enhancing environmental protection include efficient water management, improving paddy field layout, water quality management and provision of drainage facilities. These are briefly outlined next.

Water Management

Paddy fields use considerable water for crop production. It is estimated that paddy uses water anywhere from 750 mm to 1600 mm depending on local weather conditions. The water balance equation for an individual paddy field or a group of paddy fields provides an estimate of the water requirements at a given location. The water balance in a paddy field consists of the supply components like rainfall and irrigation and discharge components like evapotranspiration, runoff, seepage and percolation.

Considering an individual field as shown in Fig. 1, the water balance equation can be written as:

$$W_d^j = W_d^{j-1} + R_f^j + I_r^j - E_t^j - D_r^j - S^j - P^J \qquad (1)$$

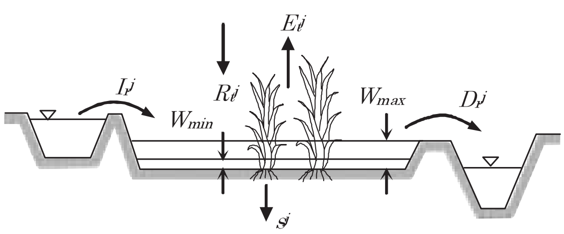

Fig. 1 Water balance components in a paddy field

where,

W_d^j = water depth in the field,
W_d^{j-1} = water depth in the field during previous time interval,
R_f^j = rainfall,
I_r^j = irrigation,
E_t^j = evapotranspirtation,
D_r^j = drainage,
S^j = seepage, and
P^J = percolation.

W_{max} refers to the maximum water depth that can be retained in the field and depths received beyond this will go to the drainage. W_{min} refers to the minimum water depth required in the field from crop production requirements. The water balance equation is applicable for any selected time period like a day, a week or a month. A day is a convenient unit for modeling purposes. Considering a given situation, the water balance model can be used for several applications like scheduling of irrigations, estimating irrigation requirements and calculating drainage quantities. An understanding and quantification of the water balance components will help in developing efficient management practices for using land and water. Integrating information from the individual field level, water balance studies help in planning the water management aspects at the watershed or regional level. In the equation of the water balance, some of the components can be measured and some need to be estimated. While rainfall and irrigation can be measured, evapotranspiration, drainage, seepage and percolation are to be estimated using climatic, soil and field layout parameters.

At the block level, in lowland situations surface runoff could be stored in the adjoining creeks/channels. The water balance equation for the creeks/channels could be written as

$$V^j = V^{j-1} + R_f^j + I_f^j + I_r^j - O_r^j \qquad (2)$$

Where,

V^j = volume available in the creeks,
V^{j-1} = volume in the creeks in the previous time step,
R_f^j = rainfall falling in the creeks,
I_f^j = inflow into the creeks from the fields, and
O_r^j = outflow from the creeks.

The volume available in the creeks depends on the geometry of the channels and the maximum permissible height in the creeks. Runoff from the fields adds to the creek volume while outflows could be due to gate operation into downstream as well as groundwater outflows. Water stored in the creeks could be used for irrigation of the paddy fields. A planned gate operation

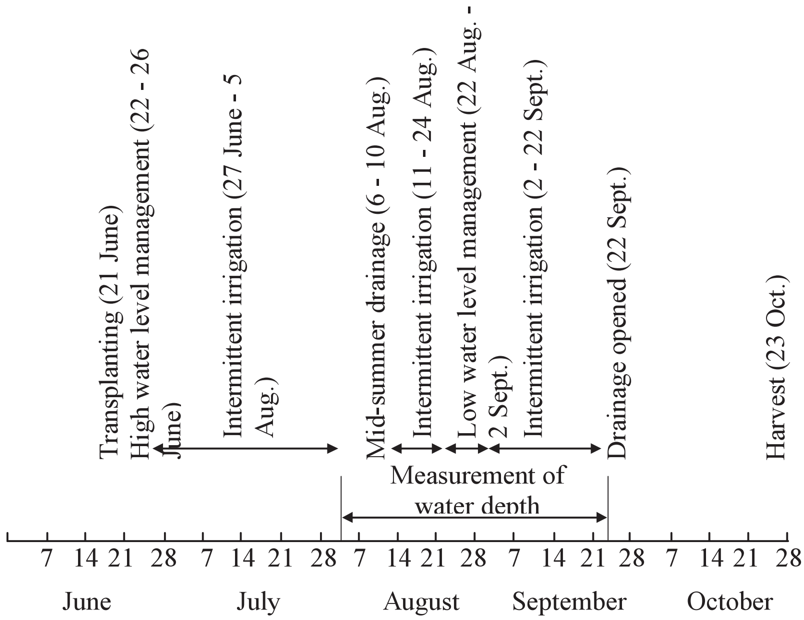

Fig. 2 Irrigation schedules observed in the selected field

Table 1 Calculation of evapotranspiration values for paddy place: Saga latitude: 33.00 N. L longitude: 1 30.00 E.L, Height above MSL = O.Om, crop coefficient= 1.2

1994	Ave.temp.	Humidity	Windspeed	Sunshine	Sol.radia	Eto	ETcrop	Etcrop
Month	^{0}C	%	km/day	hrs	MJ/m/day	mm/day	mm/day	mm/day
January	6.1	71	181	4.5	9.1	1.22	1.464	2.0
February	6.9	67	242	4.5	11.1	1.71	2.052	2.0
March	8.6	64	225	6.3	15.9	2.33	2.796	3.0
April	16.1	71	216	2.7	12.9	2.55	3.06	3.0
May	20.2	69	225	5.8	18.6	3.83	4.596	5.0
June	22.9	68	225	4.4	16.8	4.05	4.86	5.0
July	29.9	71	242	10	24.7	5.84	7.008	7.0
August	29.6	70	251	9.4	22.7	5.75	6.9	7.0
September	24.1	72	233	6.5	16.7	4.04	4.848	5.0
October	19.2	66	242	6	13.5	3.2	3.84	4.0
November	14.4	69	199	5.7	10.8	2.07	2.484	3.0
December	9	72	181	4	8.1	1.39	1.668	2.0

could help in the beneficial use of the drainage water both for re-circulation as well as for controlling water table.

Considering the evapotranspiration values given in Table 1, which were calculated for a study area in Saga, southwestern Japan, the sum of seepage and percolation losses worked out to 6 mm to 10 mm per day. There is a variation of seepage and percolation losses depending on the depth of water in the interceptor drain. The field is equipped with three sub-surface drains. These were not operated during the crop growth period except before the harvest at which time these were used to drain the water from the field so that the harvesting machines could be operated.

In the area taken for study, it was observed that irrigation supplies were given based on visual observation of water in the field. However, the water supplies were well controlled and the fields were not over irrigated. The number of irrigations given during the crop growth period is shown in Fig. 2. Each time, the water is applied up to a depth of about 3 cm only indicating that the field is not over irrigated.

The total losses from the paddy field consist of evapotranspiration, seepage and percolation. While evapotranspiration values depend on climatic parameters, the seepage and percolation losses depend on the soil properties, condition of the embankment around the paddy field and field layout. In the study area, it was observed that total water losses from the field range from around 10 mm to 30 mm per day. The daily losses are not constant during the crop season and as mentioned earlier could be influenced by several soil and layout factors. However, it can be said that the losses are within the range normally occurring in well-managed paddy fields.

Various factors influence the components of the water balance equation. These consist of soil, climatic, and crop factors in addition to the paddy field layout. Odihambo and Murty (1994) studied the water balance components in a group of rice fields and validated the water balance model for a given location in Thailand. It was also shown that the water balance components are influenced by field layout and for efficient water utilization both field layout and water deliveries are important. In a study of the water balance components in a lowland situation, Murty et al., (1998) reported the following steps for efficient use of water in paddy fields: i. use of shallow water depth for standing water in the paddy field, ii. re-circulation of drainage water, and iii. maintaining water table depth as per crop needs. The water quality aspects involved in re-circulation of water will be discussed later.

Layout of Paddy Fields

Paddy field layouts initially depend on the topographical conditions but later get modified to suit the land and water management situations. In some countries due to complex social conditions, paddy fields are divided into small and irregular plots. An examination of the field layouts in many of the Asian countries indicate the following problems or difficulties: i. Because of the irregular layouts followed, considerable land area is lost in bunds (low embankments), ii. Movement of water for either irrigation or drainage becomes difficult, iii. Utilization of rainfall is not up to the maximum possible extent.

In Japan, in plain areas, traditional paddy fields have been consolidated and have been re-laid with access roads, irrigation and drainage facilities. In hilly areas of Japan however, paddy fields exist more or less in the traditional form. The different forms of paddy field layouts are shown in Fig. 3.

Improvement in paddy field layout results in better utilization of water as well as other inputs and contributes considerably to enhance the environmental conservation factors. For example, Mogi and Motomura (1996) studied the possible mosquito control by improvements of flow rates in water channels. They suggest that engineering measures are necessary to maintain flow speeds in water channels to prevent mosquito breeding in mosquito-productive segments. While improving paddy field layouts these aspects can be considered. However, improvements in paddy field layouts require considerable investment and cooperation of the farmers owning the paddy fields. In many of the developing countries, it is very difficult to implement improved paddy field layouts.

Drainage of Paddy Fields

Drainage of paddy fields is needed for improving the soil physical properties, timely agricultural operations and to help crop diversification in rice fields. It has also been observed that drainage plays a significant role in reducing the adverse effects of paddy fields in health aspects. In respect of paddy fields, three types of drainage systems need to be considered depending on the particular situation.

i. A shallow surface drainage system for the removal of excess water from the soil surface. This consists of a network of open drains serving one or a group of fields and ultimately delivering the water to an outlet. This system is generally desirable for all rice fields except those on very pervious soils,

ii. A shallow surface drainage system combined with deep open drains. This type of system is essentially required when the water table is lowered in the root zone. Lowering of the water table might be required either for leaching purposes or when crops other than rice are proposed to be grown,

iii. A shallow surface drainage system combined with a subsurface to provide for water table control. This type of arrangement is needed when rice is cultivated under lowland conditions.

Design of surface drainage systems

Surface drainage to control the water level in the rice fields is achieved by a network of open channels serving each individual or a group of fields and finally delivering the water to the outlet. The concept of drainage coefficient or drainage modulus is used in the design of drainage systems for agricultural lands. The drainage coefficient is defined as the depth of water to be removed in a 24-hour period from the entire drainage area. It is also expressed as the flow rate per unit area. Based on the rainfall characteristics and soils, values of the drainage coefficient are determined such that no appreciable damage is caused to the crops grown in the area. Knowing the values of the drainage coefficient, the

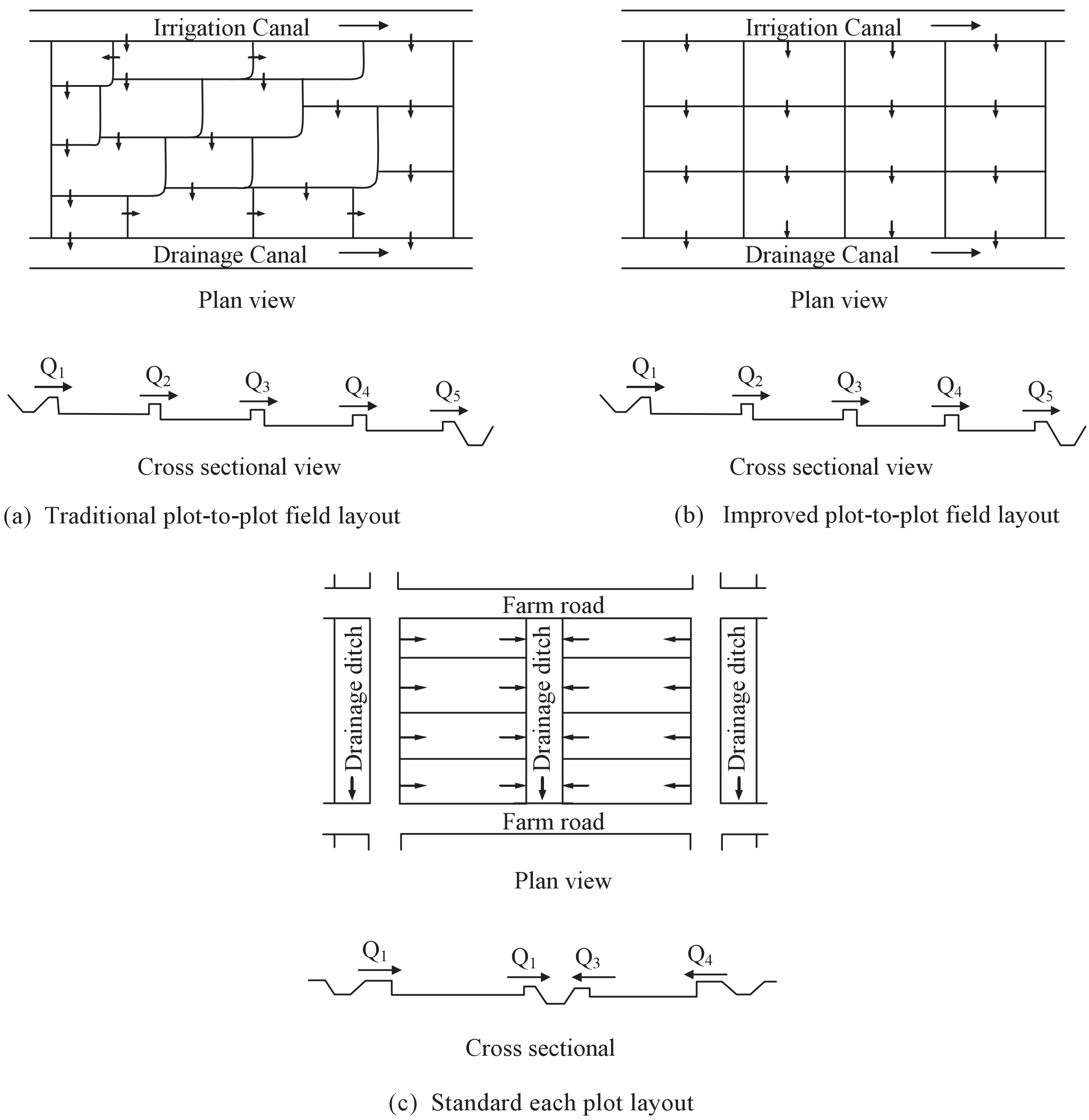

Fig. 3 Different layouts of paddy fields

drainage channels are designed based on the principles of open channel hydraulics.

The rainfall-runoff processes in low-lying watersheds with paddy fields are different from that of mountain areas where rainwater flows over different land surfaces and flows into a channel. In paddy fields, in addition to a field level surface and subsurface drainage systems, drainage at the watershed level is also important in order to prevent inundation of paddy fields during high rainfall events.

In low land paddy fields, as the topography is generally flat, at many locations, gravity type outlets may not be available and pumping stations become necessary. The capacity of the outlet is important as the water levels in the drainage channels are influenced by the levels at the outlet rather than the capacity of the drainage channels. Hayase (1992) discusses the runoff problems from paddy fields and outline a dynamic tank model that has been used for estimating runoff from watersheds with paddy fields.

Design of subsurface drainage systems

Subsurface drainage refers to the removal of excess water from the crop root zone. This is achieved by means of subsurface drains located below the soil surface. Extensive agricultural areas are under subsurface drainage in USA and the Netherlands. However, subsurface drainage of paddy fields has not been adopted on a large scale in any of the rice growing areas except in Japan. In Japan, subsurface drainage systems are being extensively installed in the rice growing areas. The design of a subsurface drainage

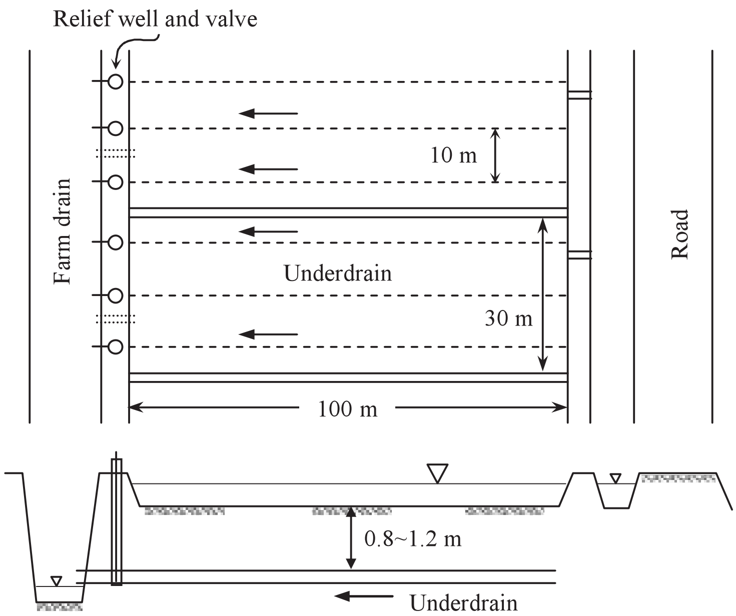

Fig. 4 Typical layout of a subsurface drainage system in rice fields

Table 2 Data of water quality parameters

Date	Sample location	BOD mg/l	COD mg/l	pH	TDS ppm	EC □s/cm	T-N mg/l	T-P mg/l
		Parameter						
18 Sept. '98	Drain	13.6	8.70	6.4	56.4	111.9	0.91	0.12
	Creek	4.23	6.81	6.6	47.2	93.9	0.39	0.08
	Irrigation	3.03	2.34	7.3	41.7	83.2	0.76	0.02
22 Sept. '98	Drain	-	-	6.9	133.3	66.9	0.33	0.07
	Field	-	-	7.1	141.5	70.9	0.89	0.19
	Groundwater	-	-	6.2	124.5	62.5	0.81	0.20

system essentially consists of determining the drainage area, spacing and depth of the subsurface drains, size and materials of subsurface drains, ancillary structures, outlets, installation procedures, and operation of the system.

The subsurface drainage systems installed in the upland irrigated areas and those installed in lowland rice fields differ in many aspects of design and functioning. The details of the installation of subsurface drainage systems in rice fields are outlined by Tabuchi (1985) and Nagahori (1989). A typical subsurface drainage system is shown in Fig. 4.

MANAGEMENT OF WATER QUALITY

The paddy field layout in the lowland area of Saga, a land area developed along the northern coastal areas of the Ariake Sea in Japan, consists of interceptor drains and modified creeks. The surface runoff from the paddy fields, surface drainage and subsurface drainage water gets collected in the interceptor drains and the modified creeks. Control gates and pumping stations are installed on the modified creeks for pumping water to the paddy fields. Irrigation water is also supplied to the creeks to augment the available water. This can be said to be an efficient system as the drainage water gets used in the field reducing the demand on irrigation water from external sources. However, water quality aspects need to be taken into consideration.

In this study area, some of the water quality parameters were observed. Frequent samples were taken from the water in the interceptor drain and the creeks. A few samples of the irrigation water and drainage water at the outlet of the creeks into the river are taken. The parameters selected for the analysis are bio-chemical oxygen demand (BOD), chemical oxygen demand (COD), pH, total dissolved solids (TDS), electrical conductivity (EC)-a measure of the water salinity, total nitrogen (T-N) and total phosphorus (T-P). The results of the water quality analysis are shown in Table 2. It can be said that the water quality observations are somewhat limited in the sense that drainage water from a single group of fields and creek water in the upper reaches of the paddy fields was only considered. The drainage water is slightly acidic as compared to the irrigation water. However, it does not appear to be a serious limitation for circulating the water for irrigation of rice fields. The total nitrogen content appears to be within the permissible limits (< 1 ppm). In the present study, no analysis has been made for pesticide residues.

As such no conclusions regarding pesticides residues can be drawn. From other constituent points of view, rice fields themselves may not contribute to serious water pollution.

In paddy fields, rainwater and irrigation water are used for crop production. Excess rainwater, irrigation return flows and drainage water resulting from intermittent irrigation and drainage practices required for crop production, generate considerable amounts of drainage water in paddy field systems. Drainage water could contain residues of fertilizers, herbicides and pesticides applied to the paddy field. Zulu et al. (1996) assessed the total nitrogen (T-N), total phosphorus (T-P), suspended solids (SS) and chemical oxygen demand (COD) in the drainage water from paddy fields. They did not observe any adverse effect on crops due to the use of the drainage water for irrigation. It was concluded that water reuse not only helped to meet irrigation water needs but also helped in purification of the drainage water and preservation of the rice land ecosystem. Several studies relating to the water quality aspects of the return flows from paddy fields were outlined by Maruyama and Tanji (1997). These are mainly related to the nutrients N and P in return flows. While the average concentrations of T-N were observed to be of the order of 2 ppm, concentrations as high as 64 ppm for T-N were observed in certain instances. Such high concentrations are of concern depending on the downstream use of the drainage water.

Table 3 Irrigation water quality standards for paddy in Japan

Item	Standard
pH	> 6.0 and < 7.5
COD	< 6.0 ppm
SS	< 100 ppm
DO	> 5 ppm
T-N	< 1 ppm
Arsenic	< 0.05 ppm
Cyanogen	practically nil
Alkyl mercury	practically nil
Organic P	practically nil
Cadmium	< 0.01 ppm
Lead	< 0.1 ppm
Chromim (VI)	< 0.05 ppm

The type of pollutants in the agricultural drainage water depends on the location of the paddy fields and the external agencies adding contaminants to the drainage water. Misawa and Kondoh (1992) observed cadmium in drainage waters added from mine drainage. Cadmium accumulates in rice and then to the consumer and could cause a particular bone disease. They proposed the following standard for irrigation water to be used for paddy irrigation (Table 3).

Paddy field drainage water could contain some amounts of pesticides and herbicides depending on the nature of drainage and time of application of the chemicals. Subsurface drainage waters generally do not contain traces of pesticides. The ultimate point where the drainage water is to be disposed off influence the impact of the quality of the drainage water. If the drainage water is discharged into any aquacultural facility, the pesticides in the drainage water are of concern as they are likely to enter the food cycle through fish. In a report relating to the health guidelines for the use of wastewater in agriculture and aquaculture, the World Health Organization (WHO, 1989) indicated that even though fish are raised in wastewaters, if the fish are well cooked they do not have any harmful effects on humans.

It is sometimes stated that the pesticides now used are biodegradable and do not enter the food chain. It can be stated that the information available about the possible effects of pesticides is not fully conclusive and further research is needed regarding any possible contamination effects of the pesticides in paddy fields.

METHANE EMISSION FROM PADDY FIELDS

Paddy fields are considered as one of the sources of atmospheric methane, a gas contributing to global warming. Table 4 shows methane emission from paddy fields estimated in different countries of the world. Most values are between 0 and 1.4 g/m2 /d. Total global annual methane from paddy fields is estimated by may researchers as from 20 to 170 million tons. However, these estimates are still very uncertain due to the lack of detailed measured data. Methane emission from paddy fields are affected by climate, water regime, soil properties and various cultural practices like irrigation and drainage, organic amendments, fertilization, etc.

Table 4 Methane emission from rice fields

Country	Measured Values $g/m^2/d$
China	0.0-1.4
India	0.0-0.5
Japan	0.0-0.4
Philippines	0.1-0.2
Thailand	0.0-0.8
USA	0.0-0.5
Italy	0.1-0.7
Spain	0.1

(Source: Minami et al., 1994)

If it is established fully that methane emissions from paddy fields add to the global warming effect, further researches are needed to reduce such emissions. In paddy fields, the presence of standing water impedes the diffusion of oxygen from the atmosphere into the soil and thus keeps it anoxic. Periodical removal of the ponded water through drainage helps in re-oxidization of the soil reducing emission of methane from the paddy fields. The practice of intermittent irrigation and drainage that helps crop production is indirectly useful for reducing the methane emissions from rice fields.

PADDY FIELDS AND HEALTH ASPECTS

Regarding environmental impacts, paddy fields have both beneficial and adverse effects. The beneficial effects include of flood retardation and sediment retention. Among the adverse effects, the important ones are contamination of water resources and health effects on the persons living near the paddy fields. In connection with the health problems, a preliminary survey has been done along the residents adjoining the paddy field areas. Many of the residents did not like the stagnant water in the creeks and expressed their view that the creeks need to be cleaned more frequently and water has to maintain flow in order to be clean. Regarding the health issues, even though it appears that mosquito problem is present, there does not appear to be any disease causing by mosquitoes.

The usual method of rice cultivation with surface flooding and soil saturation provides an ideal environment for many vector borne diseases. (The term *vector* refers to the living transporter and transmitter of the causative agent of disease). It has been recognized that rice production in developing countries is the cause of vector borne-diseases like Japanese encephalitis, malaria and schistosomiasis (IRRI, 1988). The occurrence and spread of these diseases are rather different in the various countries of the Asian region. In Japan, these have been almost eliminated or controlled satisfactorily. However, Japanese encephalitis has been reported appearing in parts of South Eastern Russia, Indonesia and Sri Lanka. Although it appears to be subsiding in China, Japan and Republic of Korea, it has been spreading in parts of Bangladesh, Burma, India, Nepal, Thailand and Vietnam. An association of rice fields with malaria vectors is established but no clear extent of the malaria transmission due to mosquito vectors that breed in rice fields has been reported. Schistosomiasis endemic in many countries appears to be transmitted through either rice fields or the irrigation systems. Methods that would limit mosquito breeding in rice fields in general could also be effective against the snail intermediate hosts of schistosomiasis.

There are some possibilities and difficulties of control of rice field vector mosquitoes by water management. The measures include water management in both the irrigation canals and rice fields. Irrigation canals should have smooth flows, lined, separated from domestic water and flushed at intervals. Unused canals and depressions need to be filled up. In rice fields in addition to providing drainage, intermittent irrigation which helps in soil drainage and drying are suggested. The need for manipulation of rice fields and associated canal networks as a whole to control of rice field vector mosquitoes by environmental management. The problem of water management, vector control and rice production has to be approached on a regional or project basis. In areas where the problems of environmental health in rice fields are identified, water management and field layout aspects have to be examined and remedial steps suggested.

CONCLUDING REMARKS

Paddy fields cover large areas particularly in Asian countries and utilize large quantities of fresh water resources. Paddy fields have both beneficial and detrimental effects on environmental aspects. The beneficial aspects include flood retardation, sediment retention and groundwater recharge. The important adverse effects consists surface and groundwater contamination, eutrophication of water bodies, health hazards in certain situations and methane emissions contributing towards global warming. While pesticides and herbicides are being used in paddy fields, at present their role in either water contamination or bioaccumulation in not fully clear and further investigations are needed. Understanding the water balance components in rice fields both at the individual field level and at a watershed level will help in improving water management practices. Most of the adverse effects of paddy fields could be mitigated by proper drainage at the individual field level as well as at the watershed level.

The layout of the paddy fields with interceptor drains and modified creeks is suitable in a lowland situation where irrigation and drainage have to be practiced. Irrigation becomes necessary due to the distribution of rainfall and drainage is important to maintain a better environment for crop growth.

In the area taken up for study, it is seen that the water balance components for growing paddy are well managed. The seepage and percolation rates are within acceptable limits and irrigation is well scheduled. In the paddy field lots, prefabricated structures have been installed for surface drainage. It is possible to utilize the rainfall better by effecting improvements in these structures.

Re-circulation of the water in the modified creeks is beneficial as it reduces the demand on external irrigation supplies. A preliminary study of the water quality of the re-circulated water indicates that the water quality is satisfactory for crop use.

In growing paddy crop, herbicides for weed control and pesticides for control of pests and diseases are being used. Even though, it is claimed that most of these chemicals are fast degrading, there is a possibility of these chemicals to be found in the drainage water. The information available now is not fully conclusive about pesticide residues and further investigations are needed to ascertain the fate of these chemicals and their influence on water quality.

The water in the interceptor drains and the modified creeks is controlled by a series of gates installed along the modified creeks. It is possible that by regulating the flow rates with the help of these structures, the stored water and also the water table depth can be regulated. A modeling approach is possible to study the mater management aspects in the modified creeks. After the water quantity aspects are considered, water quality aspects could be added.

Improvements in the pre-fabricated outlet structures for better utilization of the rainfall are possible. Even though at present there is no direct evidence of public health hazards in the paddy fields these need to be kept under consideration for constant monitoring. As the field operations are mechanized and fields are provided with drainage systems, it can be said that much of the possible health hazards have been eliminated.

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