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INFLUENCE OF GROWING ENVIRONMENTAL POLLUTION ON THE NATURAL HYDROLOGIC CYCLE

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ABSTRACT

This paper describes the influence of environmental pollution on the components of the hydrologic cycle. Water pollution in the form of dissolved solids (organic or inorganic) and oils decrease the rate of evaporation from the hydrosphere into the atmosphere. Widespread destruction of forests by man-made activities reduces the magnitude of transpiration into the hydrologic cycle. The urban heat island creates thermally induced upward motions that act to diminish the atmospheric stability. Air pollutants introduced into the atmosphere through industrial, energy production, and transportation processes, have a strong attraction for water vapour which condenses and freezes on them forming ice crystals which in turn form clouds. If sufficient moisture is there, cloud droplets grow in size and eventually fall as precipitation. However, increased particle concentration due to high atmospheric pollution will result in a large number of cloud droplets of smaller size, which do not coalesce as readily as bigger cloud droplets and by this the intensity of precipitation may be hindered. Increased industrial, urban construction and excessive dumping of solid and liquid wastes in the soil modify the surface properties and causes changes in rates of run off and infiltration.

INTRODUCTION

The hydrologic cycle is an accumulation of many climatic and hydrologic phenomena which describes the cyclic nature of water movement in the atmosphere, the hydrosphere, and the lithosphere. Solar energy induces the cycle through evapo-transpiration of water from aquatic and terrestrial surfaces. Air masses collect this water vapour and transport it into lower troposphere. When the temperature and pressure of air mass reflect the dew point in the lower troposphere, precipitation is either intercepted by vegetation, infiltered into the soil profile, or accumulated in run-off to surface water bodies where upon it is recycled again into the hydrologic cycle.

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Science has given a great deal of attention to the unending circulation of water among the three components of the environment, ie., the atmosphere, the hydrosphere, and the lithosphere. Water exists in all the three phases (ice, liquid, vapour) in the earth-atmospheric system and that transformations take place among the components of the environment. However, in recent years, the atmosphere, the hydrosphere, and the lithosphere became an infinite sink for the disposal of all kinds of wastes (solid, liquid, and gaseous) from industrial, domestic and agricultural activities (CEQ, 1976). Following the release, the waste chemical contaminants may be stored or converted to different forms and/or transformed within and between the various components of the environment and induces measurable changes in the natural hydrologic cycle. These changes are manifested in evaporation, transpiration, precipitation, surface run-off and infiltration processes which are of the principal components of the hydrologic cycle. An attempt is made in this paper to document the existing state of scientific knowledge on the influence of growing environmental pollution on the natural hydrologic cycle. Such information is of fundamental importance for all those who are concerned with the development and management of water resources.

EFFECT OF POLLUTION ON THE COMPONENTS OF THE HYDROLOGIC CYCLE

Evaporation:

Evaporation occurs from the hydrosphere, whenever the vapour pressure of some mass of water exceeds the vapour pressure in the adjacent air. The rate of evaporation is proportional to this difference in vapour pressure. Water pollution in the form of dissolved solids and oil decrease the rate of evaporation.

Dissolved solids (organic or inorganic) in the liquid system reduces the vapour pressure and hence tend to reduce evaporation approximately in proportion to the percentage of solids in solution. Sea water with 35,000 mg/l of dissolved solids (ie., 3.5 %) will evaporate 96.5 % as rapidly as fresh water, all other factors being equal (Dewiest, 1965). This phenomenon is believed to be due to a physical blocking effect at the surface of the liquid where pollutants (ions, or molecules) of the solute happen to be (Hellwig, 1979, Sewyer and Mc Carty, 1978).

Oil pollution of seas and inland water-ways due to the leakage and inadvertent spills are increasing at an alarming rate. It has been estimated that overall entering of oil (crude or rectified) into the world's oceans is approximately $6.13x10^{6}$

tonnes/year (NAS, 1975). Within coastal and inland water-ways leakages and accidental spills in U.S.A. was alone in 1975 amounted to about 100 billion litres from 10,500 incidents (CEQ, 1976). Such oil pollution of the hydrosphere locally prevents the evaporation of water into the atmosphere because of formation of oils as extensive mono-molecular layers. Further, the oil layers are insoluble, thermodynamically stable, and reduce the amount of energy emitted by the water which otherwise increases the evaporation. However, observations with the kind of oil spilled at sea have shown that the molecular structure of the oil is sufficiently irregular and the oil layer is usually perturbed by the various motions at the sea surface (La Mer, 1962). As a result, evaporation of water is expected to be reduced only in the immediate region of the spill or leakage.

On the other hand, thermal pollution of the hydrosphere from electric-power stations (both thermal and nuclear) and many industrial cooling processes increases the rate of evaporation. Due to the thermal pollution, its surface layer of water gets heated up and transformed into water vapour. This increases the saturation vapour pressure (USWB, 1941). The increase in saturation vapour pressure consequently increases the magnitude of evaporation of water into the atmosphere, as the rate of evaporation from water bodies is directly proportional to the difference between the saturation vapour pressure of water and the existing vapour pressure in the air above the water (De Wiest, 1965).

Transpiration:

Transpiration is a process in which water from moist pores and membranes in plants is discharged into the atmosphere as water vapour. Most of the transpiration is through leaf surfaces, and operates to bring nutrients to the leaves and to maintain favourable leaf temperatures inspite of strong solar radiation. As such transpiration rate depends upon the size and density of the root system. Anything which restricts the depth or vigor of roots restricts transpiration (Kohler et al., 1955).

Widespread destruction of forests by acid rains, and atmospheric contaminants like chlorine, sulphurdioxide, nitrogen oxides, ozone, and fluorides is widely reported from all over the world (Mansfield, 1976). When vegetation is subject to long term exposure to air pollutants from industrial sources (fossil fuel burnings), numerous chronic injurities to vegetation occur. The most common injuries are stunting of growth, destruction of leaf tissue, and chlorosis, a reduction and loss of chlorophyll.

Further, the industrialization has exploited forests as many of the industries are dependent on forest produce. Some of the industrial use of forest produce are in pulp and paper products timber products, cork products, furniture, textile industry, package industry, fuel wood etc. According to National Remote Sensing Agency (NRSA) reports, India is losing 1.3 million hectares of forest every year and the satellite mapping revealed the dangerously reduced forest cover to 14 per cent of total area (Reddy, 1987). Such destruction of forests directly has an impact on the decrease of magnitude of transpiration of water into the atmosphere.

Precipitation:

The water vapour produced by evaporation and transpiration will be available in the atmosphere to form clouds and to cause precipitation. Precipitation includes all forms of moisture falling from clouds such as rain, snow, sleet or hail and reach the ground. The amount of water vapour present in the atmosphere available for precipitation depends on many factors and in the lower atmosphere is highly variable. The water vapour content of air is upto 4 per cent by volume in hot humid areas, whereas in areas of inclement climate, it is upto 0.01 per cent. The entire volume of water contained in the atmosphere is 14,000 km^3 (Klimentov, 1983).

The atmosphere acquires from natural sources a number of variable trace gases (such So_2, and oxides of nitrogen) and solid particles such as dust, sea spray, and sulphates which provide nuclei for condensation and freezing to form water droplets or small ice crystals. These microscopic water droplets move across the air in the form of clouds and mist; some of them collide, coalesce and consequently start falling down; on their way down they coalesce again with other droplets, thus increasing their own volume. Under certain conditions the droplets formed in this way are no longer capable of being held in the troposphere by the ascending air flows, so consequently they fall giving rise to atmospheric precipitation (Fletcher, 1962).

However, the earth's atmosphere has become greatly polluted in recent years. Numerous observations have shown that the levels of air pollution in many cities and industrial centres have grown dozens of time and in the world at large is 20 per cent higher than at the beginning of the present century. The amount of dust which enters into the atmosphere through man-made activities is approximately 3.75×10^8 tonnes/year (SCEP, 1970). Similarly, the estimated global emissions of So_2, No_2, Co, Co_2 H_2S, and hydrocarbons through anthropogenic sources (Fossil-fuel burnings) into the atmosphere are 1.46×10^6, 5.3×10^7, 2.75×10^8, 1.4×10^{10}, 3×10^6 and 8.8×10^7 tonnes/year respectively (Robinson and Robinson, 1972).

Dust particles of several microns in size normally remain in the atmosphere for anything from a few days to a few weeks. As a result, almost all particles after being in the atmosphere for some time have accumulated water-soluble material which enables them to behave approximately as soluble nuclei. Many of the gaseous pollutants undergo secondary reactions (oxidation and hydration) and forms acid droplets (0.1 to 1.0 micron size). Oxidation of H_2S or So_2 in the presence of an excess (around 10 ppb) of free NH_3 forms $(NH_4)_2$ So_4 particles (around 0.1 micron size) which is an important constituent in acting as a cloud condensation nuclei (squares, 1966, Robinson and Robbins, 1968). Water soluble, hygroscopic dust particles and acid droplets are especially active on which water vapour condenses to form precipitable cloud droplets or making the ice phase in clouds either by nucleating super cooled droplets or by serving as centres upon which ice is deposited directly from the vapour phase (Changnon, 1969); Smith et al., 1968; Mason, 1957). The lead from automobile exhaust, when combined with any iodine that happen to be in the air to produce PbI, is a highly efficient particle that initiates the freezing of super cooled water droplets (Schaefer, 1966). As the relative humidity increases in an updraft and approaches saturation, the more effective condensation nuclei starts to grow first until from about 50 to several hundred droplets per cubic centimete are formed depending upon the rate of cooling and the availability of nuclei.

Various authors have drawn different conclusions about the potential local, regional and global effects of air pollutants on increase or decrease of atmospheric precipitation. Buishand (1979) has statistically analysed the monthly rainfall data from urbanized and rural areas in the western part of the Netherlands and concluded that there is an increase of precipitation in urban areas than in rural areas. According to him, this is possibly due to the addition of condensation nuclei (dust particles and gaseous pollutants) from urban activities. Urban air typically contains many gaseous and particulate materials, in concentrations substantially higher than those found in 'clean' rural air (Ludwig et al. 1970). Dettwieler and Changnon (1976) have also clearly shown an increase of precipitation of 25 to 30 per cent in and down-wind from certain cities such as Saint Louis, Chicago and Paris. It is concluded by these authors that an increase of precipitation is highly associated with thermal effects (Hea discharge from industrial chimneys), frictional effects (due to tall buildings) on air flows resulting in frequent updraft regions, in a localized area and modification of the low level moisture content (for instance due to changes of the natural evaporation resulting from a larger percentage of impervious surface), Changnon (1969), and Peterson (1969) have summarized the urban effects on precipitation in the US and concluded that there is an increase of precipitation in the order of 10 per cent or less.

While atmospheric pollutants can and do cause more precipitation they also have the opposite effect when clouds become so over-saturated that cause less precipitation. The Australian study by Warner (1968) has shown apparent decrease in precipitation of the order of 25 per cent. These effects have been attributed due to the extensive burning of sugar cane leaf which introduces thick columns of black smoke particles into the atmosphere. An increase in particle concentration will result in a large number of cloud droplets of small size, which do not coalesce as readily as bigger cloud droplets and consequently the probability of precipitation is hindered.

Surface Run-off:

Surface run-off is the residual of precipitation after interception, infiltration, evapo-transpiration, and storage in surface depressions, if any, have been satisfied. As such, its magnitude and distribution in time and space are dependent on t those factors plus the size, shape, roughness, type and density of vegetation of the drainage basin.

Drastic changes in surface run off will occur due to the surface modifications by mining activities, industrial and urban activities, destruction of forests, dumping of solid and liquid waste on the soil. Mining activities including large quantities of earth excavation increases the magnitude of surface depressions and decrease the rate of run-off. Increased industrial and urban construction activities reduce infiltration which in turn results in increased rate of run-off. Destruction of forests by both atmospheric pollutants and industrial use of forest produce results in increased rate of run-off compared to the forest lands (Holten et al. 1950).

Dumping of solid and liquid wastes from domestic, industrial and agricultural origin on land system increases the carbon content of the soil. An increase in carbon content of the soil increases aggregation of soil, which is inversely related to runoff volumes and sediment loss (Wischmeier and Mannering, 1965). Several investigators reported less runoff volumes from the waste applied lands (Long, 1979; Mc Caskey et al., 1971). The low runoff may be due to improved soil physical properties as a result of waste applications.

Infiltration:

Infiltration is the rate at which water enters the soil surface. The primary factors which affect infiltration rate are the character and porosity of the soil, the moisture content, the degree of compaction of the soil surface, and the presence and type of vegetation (Musgrave and Holten, 1964). All the above factors one way or the other may get affected due to soil pollution.

Excessive solid and liquid waters applied on soil may decrease the rate of infiltration (Weil and Kroontje, 1979). At high rate of application building of Na^+ and K^+ in the soils was sufficient to decrease intake rates. Soil aggregates become dispersed due to the high concentrations of Na^+ and reduces the movement of water into soil surface and through the soil matrix (Powers et al., 1975; Travis et al., 1971).

Biological clogging occurs due to accumulation of suspended solids of waste water applied and associated biological growth under anaerobic conditions, when the waste applications exceed the assimilative capacity of soils. Thomas et al (1966) studied biological clogging of sands. A sharp decline in infiltration rate coincided with the onset of anaerobic conditions as indicated by cessation of nitrification. Thus, pollution of soils reduces the overall infiltration capacity of soils.

The presence and type of vegetation have a very large influence on infiltration rate. Compared with bare soil, the leaves of vegetation offer protection from rain drop impact, the root mass perforates the soil and maintains porosity, and in many cases a surface litter is provided which further protects the soil surface and also supports biological activity which favours the maintenance of porosity. Forest vegetation has the most favourable effect upon infiltration (Holten and Kirkpatrick) 1950). Destruction of forests by man-made pollution and industrial use consequently lead to decrease in the rate of infiltration.

CONCLUSIONS

The true impact of man's activities on the hydrologic cycle can be assessed only after a fuller understanding of the complex interactions between the pollutants in all the spheres of the environment and the components of the hydrologic cycle. Complete understanding will require extensive research and sophisticated measurements. There has been considerable speculation about how air pollution may inadvertently 'seed' clouds with such nuclei, but it is not all clear whether the net effect of such seeding will be an increase or decrease in precipitation.

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